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Alan Lubell

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16. ABSTRACT

This manual contains information relating to the design of air, water and solids pollution abatement systems for the textile industry. It is intended for use by process design engineers, consultants, and engineering companies active in the design or upgrading of textile waste treatment facilities.

This manual outlines typical operations used in the manufacture of various types of fabrics as well as sources and strengths of wastewater, air pollutants and solid waste. Design information relative to pollution abatement includes in-plant control measures, equipment selection factors and emerging technology.

The major effort of this manual is directed toward design information of those techniques most widely used and fully demonstrated for pollution control in the textile industry. Advanced technology, pilot plant or demonstration data of presumptive operations, although addressed, is not covered in detail.

Water pollution control in the textile industry is the major subject covered in this manual. Portions of the manual include comprehensive descriptions and analyses of the various wastewater sources and provide the basic data for facility design. In-plant controls are described for reducing the quantity and/or strength of the wastewater, and waste treatment designs are defined.

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TEXTILE PROCESSING INDUSTRY

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NOTICE

The mention of trade names of commercial products in this publication is to present examples of environmental control systems. This does not constitute endorsement or recommendation for use by the U.S. Environmental Protection Agency; there may be other control devices that are as capable as the examples presented in this handbook.

FOREWORD

The formation of the United States Environmental Protection Agency marked a new era of environmental awareness in America. The Agency's goals are national in scope and encompass broad responsibility in the area of air and water pollution, solid wastes, pesticides, and radiation. A vital part of EPA's national pollution control effort is the constant development and dissemination of new technology.

It is now clear that only the most effective design and operation of air, water, and solids waste control facilities, using the latest available techniques, will be adequate to meet the future air and water quality objectives and to ensure continued protection of the nation's environment. It is essential that this new technology be incorporated into the contemporary design of pollution control facilities to achieve maximum benefit of pollution control expenditures.

The purpose of this manual is to provide the textile industry engineering community with a new source of information for use in the planning, design, and operation of present and future control facilities. It is recognized that there are a number of design manuals, manuals of standard practice, and design guidelines currently available in the field that adequately describe and interpret current engineering practices as related to traditional environmental control design concepts. It is the intent of this manual to supplement this existing body of knowledge by describing new pollution control methods and by discussing the application of new techniques for more effectively removing a broad spectrum of contaminants from air and water discharges.

Much of the information presented is based on the evaluation and operation of pilot, demonstration, and full-scale plants. The design criteria thus generated represent typical values. These values should be used as a guide and should be tempered with sound engineering judgment based on a complete analysis of the specific application.

This manual will be updated as warranted by the advancing state-of-the-art to include new data as they become available and to refine design criteria as additional full-scale operational information is generated.

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CHAPTER 1

INTRODUCTION

1.1 The Need for Pollution Control

A recent inventory of the textile industry conducted by Lockwood Greene Engineers, Inc., indicated that there are approximately 5,366 textile operation locations within the United States. Of this number, 1,588 of the plants contacted did not submit process data. Based upon an employee count of the no data group, it is estimated these no data mills represent less than 18% of the industry and less than 12% of wet manufacturing. Of the 3,778 plants which did submit data, 1,926 plants indicated some type of wet manufacturing process, including slashing operations, and 1,852 indicated either dry process manufacturing or had no manufacturing at all. Figure 1-1 illustrates the industry distribution found by this inventory.

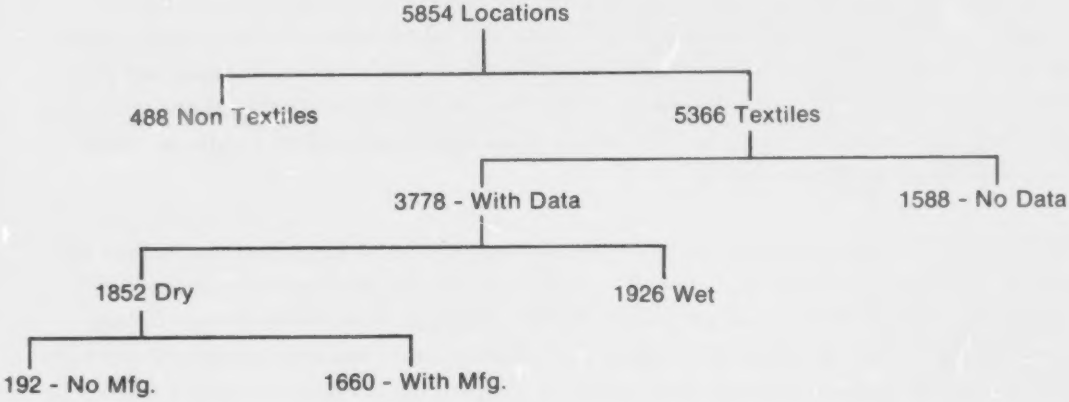

FIGURE 1-1
TEXTILE INDUSTRY DISTRIBUTION

Pollution by air emissions and wastewater effluents from many of the 5,366 textile mills presents an environmental problem in several regions of the United States. Large volumes of wastewater are generated, and treatment is sometimes difficult because of the character of the waste.

Textile processing plants utilize a wide variety of dyes and other chemicals such as acids, bases, salts, wetting agents, retardants, accelerators, detergents, oxidizing agents, reducing agents, developers, stripping agents, and finishes. Many of these are not retained in the final textile product but are discarded after they have served their purpose or are driven off into the atmosphere during heat treatment. The liquid waste effluent and the atmospheric exhaust of a textile plant may, therefore, contain any combination of such materials. Also, since many textile processes are handled on a batch basis, concentrations of waste materials may fluctuate widely. Specifically, with regards to textile waste, solids may be present from fibrous substances, process chemicals, and also as a result of biological wastewater treatment. The solids can affect the natural aquatic environment by hindering oxygen transfer and reducing light penetration. Solids that settle on the stream bottom can cover the flora and fauna and result in an anaerobic sludge layer.

Organic substances in textile waste such as dyes, starches, and detergents are another form of pollutant which may undergo chemical or biological changes and consume dissolved oxygen from the receiving water. Such organic substances should be removed to prevent septic or low dissolved oxygen conditions and obnoxious odors and to avoid rendering the receiving water unsuitable for municipal, industrial, agricultural, residential and recreational use.

The presence of inorganic salts in high concentrations may make the receiving water unsuitable for most industrial and municipal uses. Foaming from detergents and colors from dyes are esthetically objectionable, particularly in drinking and recreational waters. Certain carrier chemicals used in dyeing, such as phenols, add tastes and odors. Metal toxicity from inorganic salts of chromium and zinc can be harmful to aquatic life if it does occur. Nitrogen and phosphorous from dyes may cause eutrophication problems in receiving waters. In many instances, even the pH of the textile dyeing and finishing wastes could cause problems in the receiving streams by upsetting the ecosystem.

Thermal wastes, such as cooling waters, are another source of pollution. Heat may reduce the amount of oxygen by increasing the consumption of oxygen by biota in the receiving water and decrease the saturation concentration of dissolved oxygen. Also, thermal waste is detrimental to cool water loving species of aquatic life. Perhaps more important to aquatic life is an upset due to fluctuation of temperature caused by the periodic discharge of cooling water into the receiving streams. As a result sensitive organisms could be eliminated causing an imbalance in the biological community.

In the textile industry, some processes require highly acid conditions while others are highly alkaline. Consequently, wastewater pH can vary greatly over a period of time, and some form of neutralization and/or equalization is necessary. The degree of neutralization/equalization will depend upon the extremes of the pH and the alkalinity/acidity of the wastewaters. Biological wastewater treatment inherently provides an effluent with acceptable pH for discharge to the receiving stream.

Grease and oil are harmful to biological systems as well as being aesthetically damaging to the environment; therefore, concentrations in the effluent should be limited. They are especially prevalent in wool scouring processes. Often sanitary waste is treated with the industrial wastewaters necessitating the control of bacteria and viruses. Chlorination may be needed with fecal coliform limits based upon sanitary system guidelines.

Operational difficulties in a conventional waste treatment plant may be caused by the presence of compounds upsetting to treatment plant biota or by fluctuations in the concentration of components of the waste. Poor results are obtained when materials resistant to biological attack are passed through biological treatment processes. Such inadequately treated effluents have very deleterious effects on receiving streams, and the situation is intensified when the stream flow is small or industry is concentrated in a particular area.

The most significant sources of possible air pollution in the textile industry are the various heat treatment processes, such as tentering, texturizing, drying, curing, etc., which cause boil-off of previously applied skimming oils, plasticizers, dye carriers, and finish chemicals. These condense into opaque, or odorous, and often corrosive mists called blue haze.

Solvent processes, such as solvent scouring and dyeing, can release solvent vapors if the recovery system is not working properly. Carriers for polyester dyeing, formaldehyde from resin finishes, and commonly released chemicals may cause odor problems. Dust and lint are released by virtually every operation, especially by those preceding skimming.

The textile industry is dynamic with constantly changing manufacturing processes and resulting wastewaters and atmospheric exhausts.

1.2 Scope of Manual

This manual contains information relating to the design of air, water and solids pollution abatement systems for the textile industry. It is intended for use by process design engineers, consultants, and engineering companies active in the design or upgrading of textile waste treatment facilities.

This manual outlines typical operations used in the manufacture of various types of fabrics as well as sources and strengths of wastewater, air pollutants and solid waste. Design information relative to pollution abatement includes in-plant control measures, equipment selection factors and emerging technology.

The major effort of this manual is directed toward design information of those techniques most widely used and fully demonstrated for pollution control in the textile industry. Advanced technology, pilot plant or demonstration data of presumptive operations, although addressed, will not be covered in detail.

Water pollution control in the textile industry is the major subject covered in this manual. Portions of the manual include comprehensive descriptions and analyses of the various wastewater sources and provide the basic data for facility design. Inplant controls are described for reducing the quantity and/or strength of the wastewater, and waste treatment designs are defined along with information for proper equipment selection.

1.3 Sources of Information and References

Much of the basic information and data in this manual was taken from previously published EPA documents. Chapter 3 entitled "Categorization of the Textile Industry" was written based on the information contained in: (1) the *Federal Register*, Friday, July 5, 1974, Volume 39, Number 130, Part II, Environmental Protection Agency, Textile Industry Point Source Category; Effluent Guidelines and Standards and Corrections in Volume 39, Number 163, Wednesday, August 21, 1974 and (2) the *Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Textile Mills Point Source Category*, U.S. Environmental Protection Agency, June, 1974.

The "Blue Book" developed by the Institute of Textile Technology and Hydroscience, Inc. entitled *Recommendations and Comments for the Establishment of Best Practicable Wastewater Control Technology Currently Available for the Textile Industry* for the American Textile Manufacturers Institute, Inc. and the Carpet and Rug Institute also provided very informative and useful information.

Chapter 4, entitled "Sources and Strengths of Textile Wastewater," was based on three excellent publications developed under EPA contract. The majority of the basic data is taken from work by Arthur D. Little, Inc. and described in their report to the EPA entitled *Industrial Waste Studies Program, Textile Mill Products*. Work by Dr. John J. Porter of Clemson University for the EPA entitled *State of the Art of Textile Waste Treatment* was also invaluable in providing the data summarized in Chapter 4. The third publication developed for the EPA which provided much information was prepared by Metcalf & Eddy, Inc., Engineers and entitled *Upgrading Textile Operations to Reduce Pollution.* Although other publications were used in the development of the basic data chapters of this manual, the aforementioned documents are highly recommended for additional reading.

Chapter 5, entitled "The Waste Survey," was taken from the EPA publication entitled *Upgrading Textile Operations to Reduce Pollution* and was prepared by T.L. Rinker of Blue Ridge – Winkler Textiles, Bangor, Pennsylvania.

Chapter 6, entitled "Inplant Controls," was prepared by the Institute of Textile Technology located in Charlottesville, Virginia.

Chapters 7 and 8, involving wastewater treatment were based upon Lockwood Green's in-house expertise, discussions with mill engineers, equipment manufacturers and previous EPA publications in this subject area.

Special recognition is due to Joseph W. Masselli, Nicholas W. Masselli and M.G. Burford of Wesleyan University for their continuing work in the textile industry. Much of each document mentioned above is based on data and information provided by them.

Chapter 9, entitled "Air Pollution", was based in part on the references listed at the end of the chapter. It also relies on information obtained in communications from mill personnel, equipment vendors, state and federal enforcement officers, and on the personal experience of the chapter author. The author is especially indebted to Mr. John Romans and Mr. Jim Hawkes of the North Carolina State Board of Water and Air Resources, Mr. Michael R. Beltran of Beltran Associates, and Mr. Raymond Allen of Deering Milliken, Inc.

CHAPTER 2

TREATMENT REQUIREMENTS

2.1 Introduction

The degree of treatment required prior to the discharge of textile waste is dependent upon several factors. If discharge is into a receiving stream, state, regional, federal, or any combination of all three agencies may become involved in dictating the effluent characteristics of the treated waste flow. If, on the other hand, discharge is into a municipal sewer system, the local municipality may become the governing agency.

At the present time, the federal enforcement agency (EPA) governs waste discharges by restricting the pounds of pollutants discharged based on pounds of product produced. The concentration of pollutants allowed in the effluent is therefore dependent upon the amount of water used in producing the particular product. The EPA approach provides a basic level of treatment and also promotes the conservation of water during manufacturing. The EPA guidelines do not account for receiving stream size and quality. However, by providing stream quality limitations the Regional or State agencies protect those streams which do not have the ability to assimilate those pollutants allowed under the EPA guidelines. In cases where stream quality protection is required, the effluent limitations on pollutants are generally more stringent than those established by EPA. In addition to closer regulation of effluent concentrations, many State pollution control agencies may impose additional controls which include limitations of additional specific pollutants or limitations of the quantity of waste discharged based on the receiving stream 7 day 10 year (7Q10) low flow.

Local regulatory agencies such as sewer districts, municipalities, etc., often require a greater degree of treatment than either the Federal or State Authorities. Local ordinances may prohibit the discharge of any metal ions, severely limit the quantity of color, temperature or even BOD and suspended solids.

2.2 EPA Industrial Guidelines

Discharge of industrial wastewaters is regulated by the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) as amended by The Clean Water Act of 1977. The Act provides for the establishment of nationally applicable effluent limitations on an industry-by-industry basis.

The Clean Air Act of 1970 specifies standards of performance for new stationary sources (Section 111) and emission standards for hazardous air pollutants (Section 112). The Clean Air Act Amendments of 1977 (PL95-95) made extensive changes in the Clean Air Act; however, specific federal standards for the textile industry have not been promulgated to date.

The purpose of this manual is to provide the latest multi-media technology for the textile industry. It is not intended to provide enforcement or regulatory guidance. The reader should contact the agency representatives that have responsibility in these areas. The EPA organizational structure shown in Figure 2-1 will assist the reader when requiring information beyond the scope of this report.

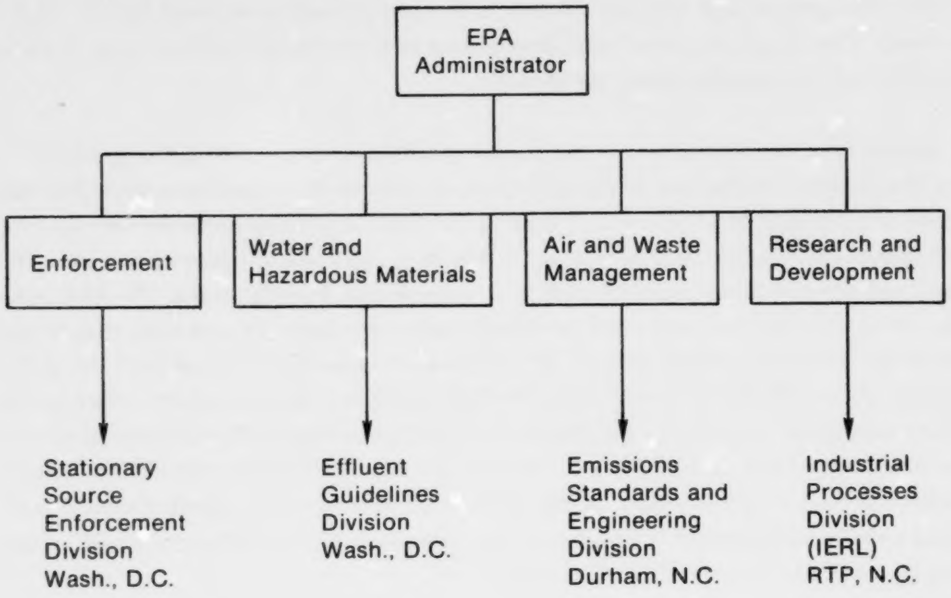
EPA Administrator
Enforcement
Water and Hazardous Materials
Air and Waste Management
Research and Development
Stationary Source Enforcement Division Wash., D.C.
Effluent Guidelines Division Wash., D.C.
Emissions Standards and Engineering Division Durham, N.C.
Industrial Processes Division (IERL) RTP, N.C.

FIGURE 2-1
EPA ORGANIZATION CHART

2.3 State, Basin and Regional Water Quality Standards

Most states have passed laws which establish agencies whose responsibility includes protection of the state's natural water resources. These agencies are empowered to establish standards for the state's waters and determine the public use or benefits to which the waters may be put. In determining the quality of the waters, the state is also empowered to determine those causes which tend to create a condition of pollution. By doing this, the state has the power to determine if a specific discharge is creating conditions of pollution within the waters or limit the amount of pollutants discharged based on the established water quality of the stream. It should be noted that effluent limits for water quality limited discharges may in fact be more stringent than those limits set forth in the Federal Register guidelines. These situations must be evaluated on a case-by-case basis.

Most states have not developed specific effluent limitations for industrial discharges, but establish discharge criteria based on existing stream conditions and water quality standards. Therefore, two similar manufacturing plants may encounter different limitations depending upon their geographic location.

A summary of the water pollution laws of twelve states wherein the majority of the textile industry is located has been summarized in a previous EPA publication, entitled "State of the Art of Textile Waste Treatment," by Dr. John J. Porter, Clemson University. Of common concern is the maintenance of sufficient dissolved oxygen (D.O.) in the receiving stream.

2.4 Pretreatment

Federal regulations regarding pretreatment of textile wastes have to date only been proposed. Generally, limits are set for discharge of "incompatibles" identified as COD, oil and grease, total chromium, phenol and sulfide. Depending upon the nature of the particular mill's effluent and the capabilities of the public facilities to remove these incompatibles, it may require the same kind of capital investment in control facilities for plants discharging into municipal systems as will be required for direct dischargers.

In addition, the discharger to publicly owned treatment works (POTW) involved in Federal construction grant assistance is subject to both a user charge and capital recovery payments to the municipality.

For situations where the municipality is in the facilities design stage, consideration should be given to providing the type of treatment compatible with textile waste, thus avoiding possible duplication of treatment facilities later.

CHAPTER 3

CATEGORIZATION OF THE TEXTILE INDUSTRY

3.1 Introduction

The textile industry is a group of related industries which uses natural and/or synthetic fibers to produce fabric. The industry uses many different raw materials to produce a great variety of products. Categorization of the textile industry into its various components can utilize one of several methods.

The classical method of categorizing the textile industry involves grouping the manufacturing plants according to the fiber being processed, i.e., cotton, wool or synthetics (See Figure 3-1). This approach may be useful when describing the individual production processes involved in making different fabrics and the associated waste produced by each unit operation; however, this method was judged to be too difficult to implement. Other methods such as the use of SIC codes or synthesizing waste loads by additive contribution from chemicals used were also judged to be unwieldy and unmanageable. Another approach to textile industry categorization involves grouping the manufacturing plants according to their particular operation, e.g., dry processing, knit fabric finishing, carpet, etc. This is the method of categorization recommended by the Institute of Textile Technology (ITT) and Hydroscience, Inc. in a report prepared for the American Textile Manufacturers Institute, Inc. (ATMI) and the Carpet and Rug Institute (CRI) (1). This method of industry categorization has also been adopted by the United States Environmental Protection Agency to describe effluent limitation guidelines and new source performance standards for the Textile Industry Point Source Category as outlined in Part II Volume 39, Number 130 of the Federal Register. Although the ITT-Hydroscience report and the EPA document are slightly different in categorization approach, for the purpose of this manual, those categories established by EPA will be used. A listing of the EPA and ATMI/CRI categories is given in Table 3-1. This chapter will describe each of the EPA categories and the unit operations that determine their classification.

3.2 Categorization by Mill Operation

The principal basis for categorization by mill operation is the configuration of principal fiber after processing. Knit and woven fabrics are different and each is different from carpet, yarn or other processed fiber. Although it is recognized that there may be different ways to produce knitted fabric, or carpet, or other textile products, there is a distinguishing similarity between the products in each of the separate categories. It is the similarities of these products that allow categorization on a mill operation basis.

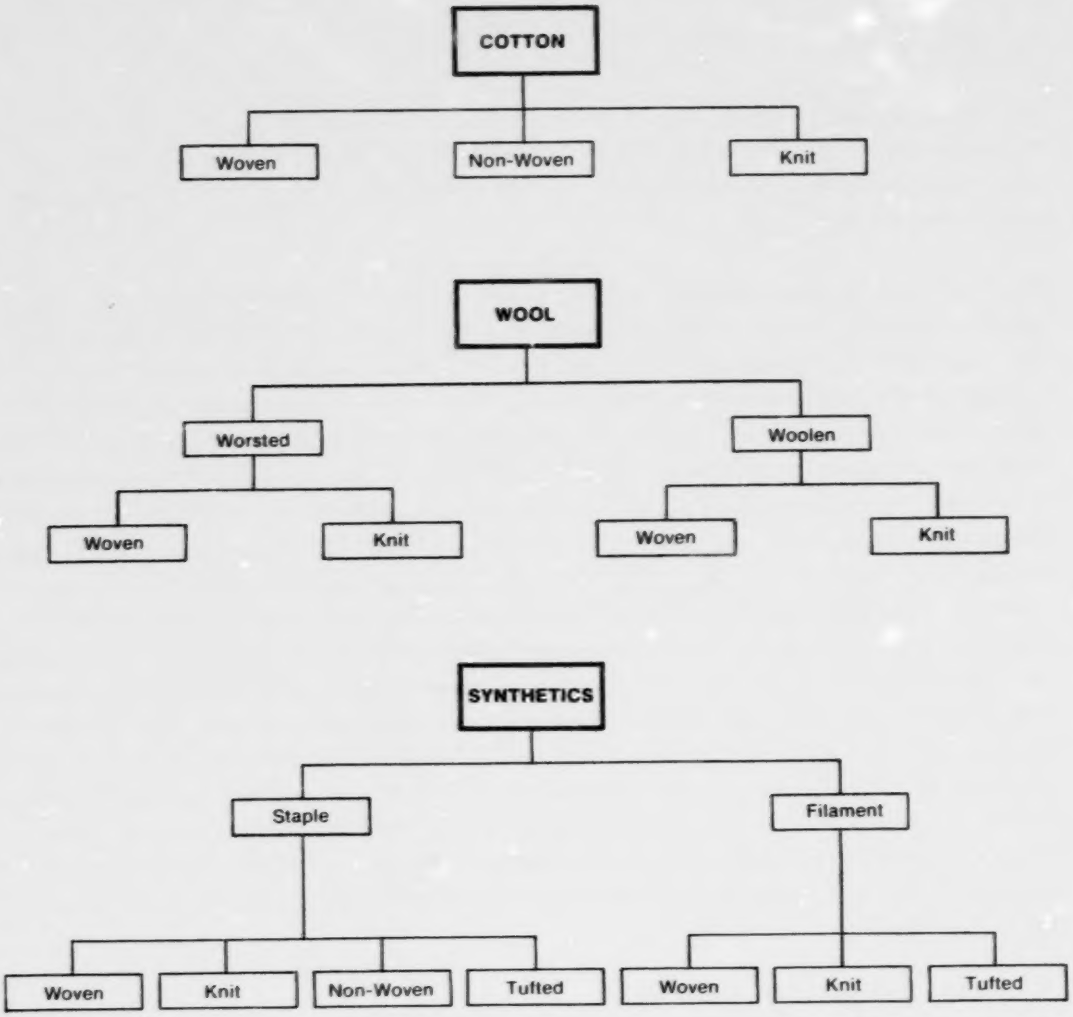
COTTON
Woven
Non-Woven
Knit
WOOL
Worsted
Woolen
Woven
Knit
Woven
Knit
SYNTHETICS
Staple
Filament
Woven
Knit
Non-Woven
Tufted
Woven
Knit
Tufted

FIGURE 3-1

TEXTILE INDUSTRY CATEGORIZATION BY FIBER PROCESSED

TABLE 3-1
TEXTILE INDUSTRY CATEGORIZATION BY MILL OPERATION

EPA	ATMI-CRI (ITT-Hydroscience)
1. Wool Scouring	1. Wool Scouring
2. Wool Finishing	2. Wool Finishing
3. Dry Processing	3. Greige
4. Woven Fabric Finishing	4. Woven Fabric Finishing
5. Knit Fabric Finishing	5. Knit Fabric Finishing
	6. Greige Mill + Finishing Fabric
6. Carpet	7. Carpet Backing & Foam
	8. Integrated Carpet
7. Stock & Yarn, Dyeing & Finishing	9. Stock & Yarn Dyeing & Finishing
	10. Greige Mill + Finishing Yarn & Fabrics
	11. Combined Materials Finishing, Stock, Yarn Wovens, Knits
	12. Multiple-Operation, Commission House
	13. Specialized Finishing

The categories to be used in the development of this manual are as follows:

1. Wool Scouring Mill
2. Wool Finishing Mill
3. Dry Processing Mill
4. Woven Fabric Finishing Mill
5. Knit Fabric Finishing Mill
6. Carpet Mill
7. Stock and Yarn Dyeing and Finishing Mill

Almost all wool processing (except carpet manufacturing) is covered by Categories 1 and 2; most cotton and synthetic manufacturing is covered by Categories 3, 4, 5 and 7; and the carpet industry is covered by Categories 3 and 6. These categories are described in detail on the following pages.

3.2.1 Wool Scouring Mill

This category of the textile industry includes the following types of mills: wool scouring, topmaking, and general cleaning of raw wool. Wool scouring is conveniently separated from other segments of the textile industry because of its uniqueness. Raw wool must be cleaned by wet processes before the fiber can be dry processed to produce fiber, yarn or fabric. Neither cotton nor synthetic fibers require this initial wet cleaning before processing. The number of plants which perform this function alone and the geographic separation from other textile operations also conveniently make wool scouring an individual category.

A generalized flow diagram of the wool scouring process is shown in Figure 3-2. Scouring consists of first sorting the fleece and feeding it to a hopper. The wool then is carried through a series of scouring bowls where scour liquor flows counter-current to it. Detergent is added in the third and fourth bowls to emulsify the grease and oils. The scoured wool is then dried. In mills where the cleaned wool is converted into wool top, the wool is combed and gilled. The products are short fibers (used for wool yarn) and long fibers (used for wool top).

3.2.2 Wool Finishing Mill

This category of the textile industry includes wool finishing, including carbonizing, fulling, dyeing, bleaching, rinsing, fire proofing, and other such similar processes. Wool finishing has been differentiated from other finishing categories because of: (1) the wide variety of chemicals used to process wool fabrics; and (2) a high raw wastewater pollutant loading. Wool finishing involves the use of specialized dyes peculiar to wool fiber, which often results in the presence of chromium in the waste. In addition, phenols often occur from dyeing wool-polyester blends.

This industry consists of many small mills, most of which are located in New England, New York and New Jersey, as well as about 25 large mills located primarily in Virginia, the Carolinas, and Georgia. Few of today's wool finishing mills process wool fabrics exclusively. Many wool finishing mills handle 20% or less wool with the balance being woven or knit synthetics. Also, within the 20% or less portion, wool synthetic blends usually constitute the bulk of the fabric (2).

The wool finishing process is depicted in Figure 3-3. The three distinct finishing processes are shown as stock, yarn and fabric finishing. Because the pollution generated by the fabric finishing operation is similar to that generated by the other two, only fabric finishing is included in this discussion. If the greige goods are 100% wool, they are first cleaned of vegetable matter by carbonizing and then cleaned of spinning oils and any weaving sizes by a light scour. The 100 % woolens are then dimensionally stabilized, principally by "fulling" or mechanical working of the wet fabric in the presence of detergents, to produce a controlled shrinkage or "felting." Worsted and most wool-synthetic blends are not fulled. Worsted are hard, tightly woven and dimensionally stable as received at the finishing plant; woolens are loosely woven, soft and often are firmed up by fulling.

The fabric is then dyed in batches in vessels called becks, washed in the same vessels, and taken to dry finishing operations. The only dry finishing operation of concern to water pollution is mothproofing.

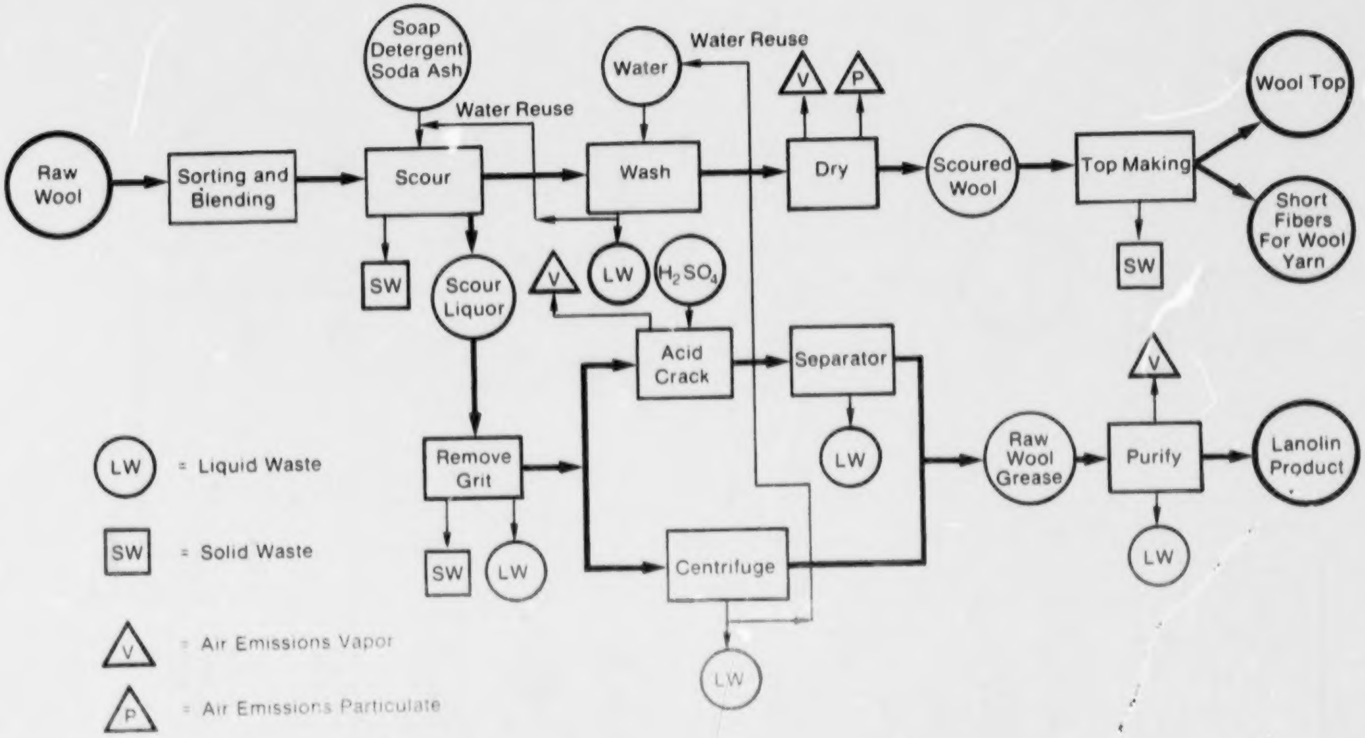
Raw Wool
Sorting and Blending
Soap Detergent Soda Ash
Water Reuse
Scour
SW
Scour Liquor
Water
Water Reuse
Wash
LW
V
H₂SO₄
Acid Crack
Dry
V
P
Scoured Wool
Separator
LW
Remove Grit
SW
LW
Centrifuge
LW
Raw Wool Grease
Top Making
SW
Wool Top
Short Fibers For Wool Yarn
V
Purify
LW
Lanolin Product
LW = Liquid Waste
SW = Solid Waste
V = Air Emissions Vapor
P = Air Emissions Particulate

FIGURE 3-2

WOOL SCOURING MILL

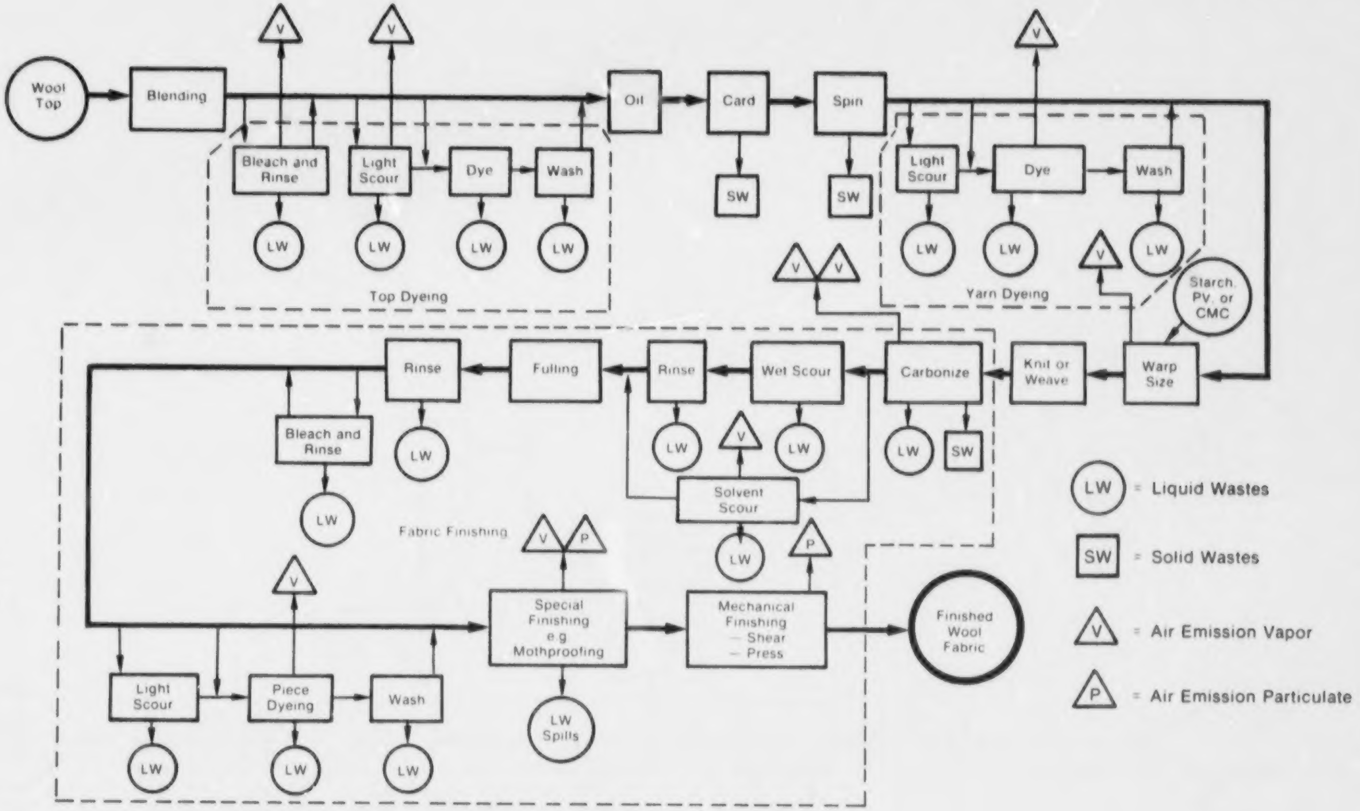
Wool Top
Blending
V
V
Bleach and Rinse
Light Scour
Dye
Wash
LW
LW
LW
LW
Top Dyeing
Oil
Card
SW
Spin
SW
V
Light Scour
Dye
Wash
LW
LW
V
LW
Yarn Dyeing
Starch, PV, or CMC
V
V
Warp Size
Knit or Weave
Carbonize
LW
SW
Wet Scour
LW
Rinse
LW
V
Solvent Scour
LW
Fulling
Rinse
LW
Bleach and Rinse
LW
Fabric Finishing
V
P
P
V
Light Scour
Piece Dyeing
Wash
LW
LW
LW
Special Finishing e.g. Mothproofing
LW Spills
Mechanical Finishing — Shear — Press
Finished Wool Fabric
LW = Liquid Wastes
SW = Solid Wastes
V = Air Emission Vapor
P = Air Emission Particulate

FIGURE 3-3

WOOL FINISHING MILL

3.2.3 Dry Processing Mill

This category of the textile industry includes the following types of mills; yarn manufacture, yarn texturizing, unfinished fabric manufacture, fabric coating, fabric laminating, tire cord and fabric dipping, carpet tufting, and carpet backing. Mills within the dry processing category typically carry out dry type operations; however, some waste is produced due to spillage and clean-up.

Since the majority of the dry processing mills listed above are "greige" mills, and due to the similar dry nature of carpet backing operations to greige mills, only greige mills will be included in this discussion. It has been estimated that there are 600 to 700 greige woven mills in the United States, 80% of which are in North Carolina, South Carolina, Georgia, Alabama and Virginia (2). Greige mills generally manufacture yarn and unfinished fabric. In general, Greige mills include the production of yarn, woven greige goods, and knit greige goods. However, knit greige goods production is almost always combined with a finishing operation and therefore is included in the knit finishing category.

Although there are many greige goods mills, they carry out mainly dry operation (with the exception of slashing) and hence contribute little to the overall waste problems of the textile industry.

Weaving textile yarns into a fabric requires application of size to the warp yarns in order to resist the abrasive effects of the filling yarns as these are positioned by the shuttle action of the loom. Greige mills apply the size and complete the weaving. Many greige mills operate as completely independent facilities. Figure 3-4 shows operations generally performed at this type of greige mill.

Weaving is a dry operation, but is normally done in buildings maintained at high humidity. Under these conditions, the size film is flexible, and yarn breaks on the loom are minimized. Yarns sized with polyvinyl alcohol may be woven at a somewhat lower humidity than yarns sized with starch. Cooling and humidifying water used in a greige mill represents a substantial portion of the total water usage. Industrial wastes generated from knit greige goods is generally nil. If any wastes are generated through spills, wash up or possible washing of the final product, the only pollutant would be knitting oils.

3.2.4 Woven Fabric Finishing Mill

This category is one of the most important, because such plants constitute much of the wastewater effluent load in the textile industry. Integrated woven fabric finishing mills are included in this category because the greige goods section of these mills contributes only a small amount of the overall effluent load.

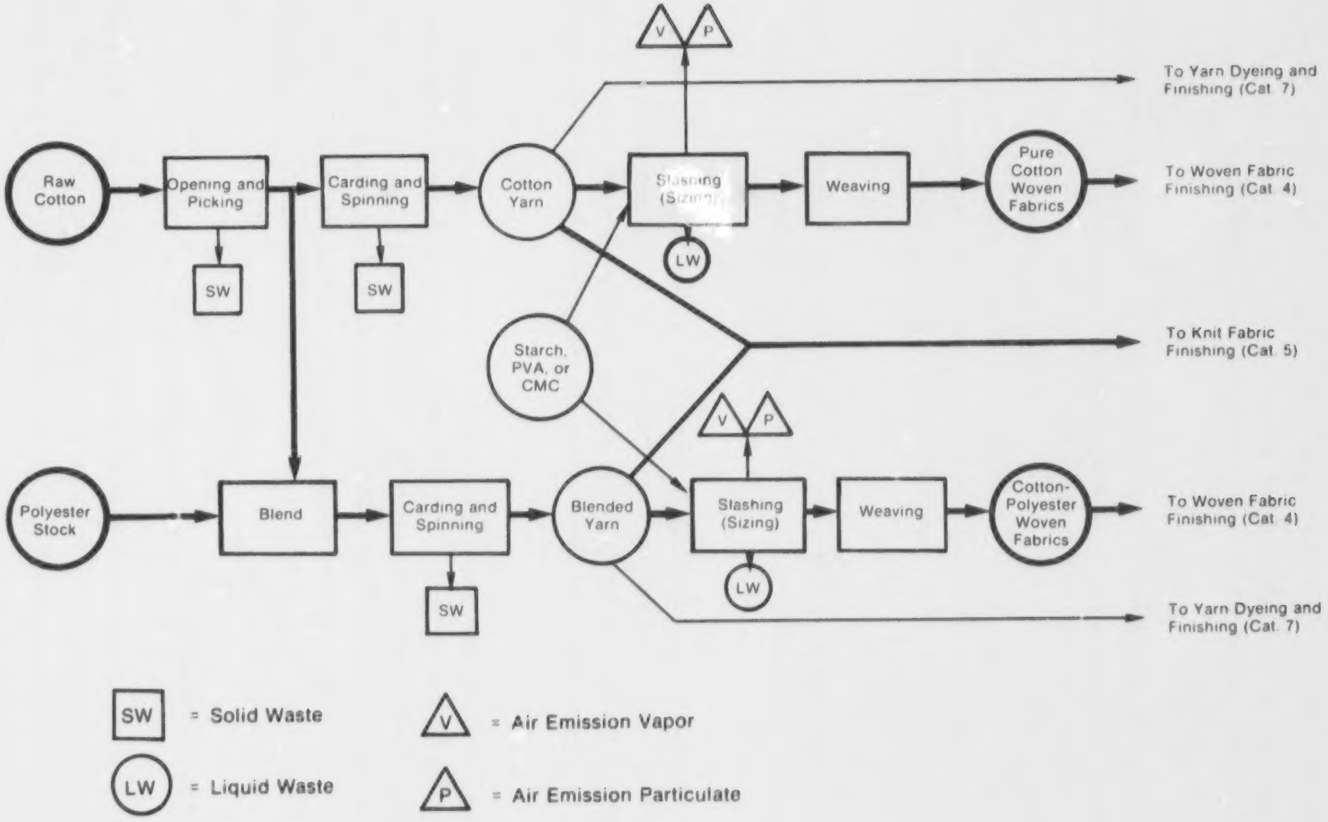
Raw Cotton
Opening and Picking
SW
Carding and Spinning
SW
Cotton Yarn
V
P
Slashing (Sizing)
LW
Weaving
Pure Cotton Woven Fabrics
To Yarn Dyeing and Finishing (Cat. 7)
To Woven Fabric Finishing (Cat. 4)
Starch, PVA, or CMC
To Knit Fabric Finishing (Cat. 5)
Polyester Stock
Blend
Carding and Spinning
SW
Blended Yarn
V
P
Slashing (Sizing)
LW
Weaving
Cotton-Polyester Woven Fabrics
To Woven Fabric Finishing (Cat. 4)
To Yarn Dyeing and Finishing (Cat. 7)
SW = Solid Waste
LW = Liquid Waste
V = Air Emission Vapor
P = Air Emission Particulate

FIGURE 3-4

DRY PROCESSING MILL

This category is characterized by the following unit operations: desizing, scouring, bleaching, mercerizing, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency application and application of special finishes. This category encompasses mills which finish woven goods (or integrated greige goods and finishing mills) and it has been estimated that about 600 mills fall into this category. This category predominates in the Southeast (North and South Carolina, Georgia, Virginia, Alabama), but there are some large operations in New York and New England (2).

Wet processes which are used in finishing woven greige fabric may be divided into two groups: those used to remove impurities, clean or modify the cloth; and those in which a chemical is added to the cloth.

The first of these groups includes desizing, scouring, bleaching, mercerizing, carbonizing and fulling. Only cotton and cotton blends are mercerized. The last two of these processes are used only on wool and wool blends.

The second group of processes includes dyeing, printing, resin treatment, water proofing, soil repellency and a few special finishes whose use represents a very small proportion of the total.

Certain fabrics, including denims and some drapery goods, are "loom finished." In production of these goods, the warp yarns are dyed, woven to a fabric, and the fabric finished with a permanent size. For these fabrics, the first group of processes listed above (cleaning and preparing the cloth) is avoided entirely. The degree of finishing necessary to provide fabric ready for sale depends significantly on the fiber(s) being processed. The natural fibers (cotton and wool) contain substantial impurities, even after they have been woven as greige goods, and require special treatments to convert them to the completely white, uniformly absorbent form that is essential for dyeing, resin treatment, etc. Synthetic fibers contain only those impurities that were necessary for manufacture of the fiber and spinning to obtain yarn. A flow sheet for woven fabric finishing is given in Figure 3-5.

3.2.5 Knit Fabric Finishing Mill

The knitting industry is characterized by a large number of plants and a structure organized along specialized product segments. The major segments are knit fabric piece goods, hosiery, outerwear, and underwear. The knit fabric finishing mill category is characterized by the following unit operations: bleaching, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency application and application of special finishes.

While the industry has shown substantial growth in value of shipments, it has been estimated that through consolidation and other factors the current number of plants in this industry is about 2500. Of this number, it has been estimated that about 1100 plants have only dry operations (2). These are plants such as sweater mills in the outerwear segment, knit goods made from purchased or commission dyed yarns, or mills which have finished goods subsequently dyed on

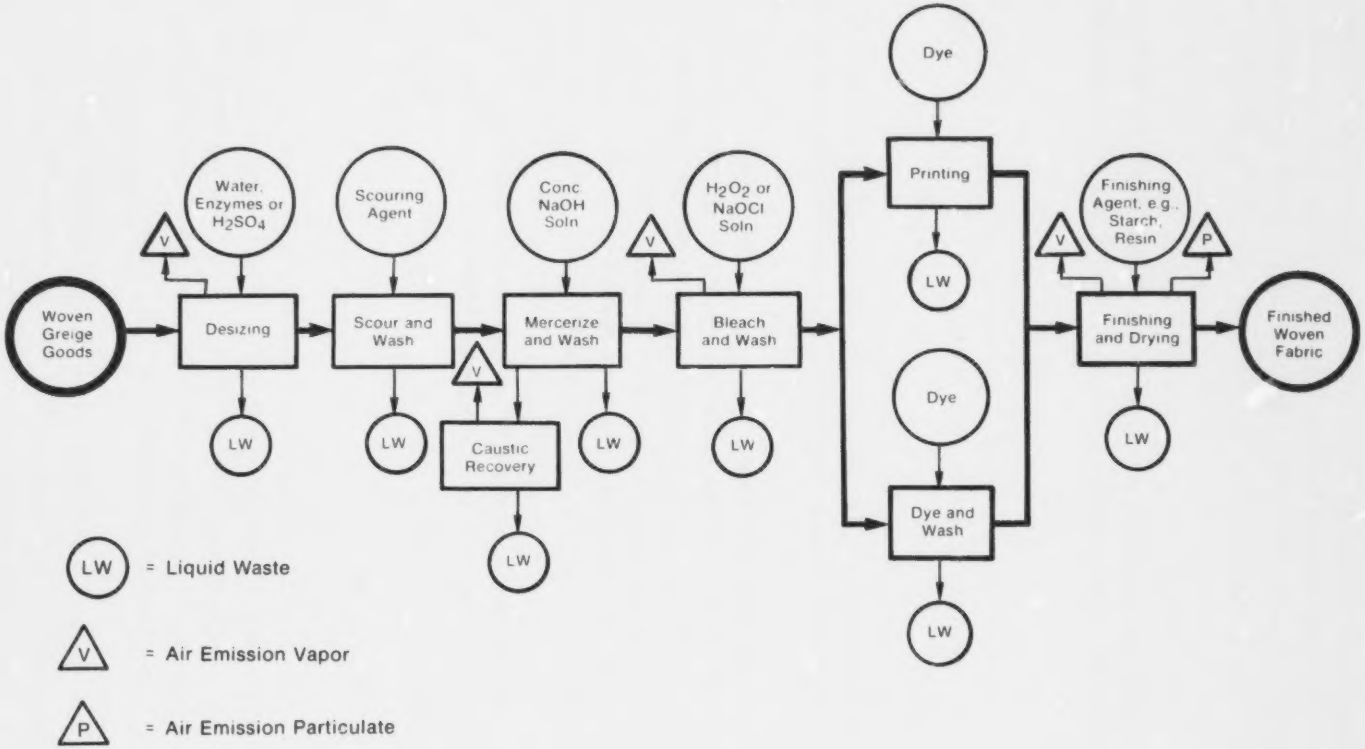
Woven Greige Goods
Water, Enzymes or H_2SO_4
V
Desizing
LW
Scouring Agent
Scour and Wash
LW
V
Conc NaOH Soln
Mercerize and Wash
Caustic Recovery
LW
LW
V
H_2O_2 or NaOCl Soln
Bleach and Wash
LW
Dye
Printing
LW
Dye
Dye and Wash
LW
V
Finishing Agent, e.g., Starch, Resin
P
Finishing and Drying
LW
Finished Woven Fabric
LW = Liquid Waste
V = Air Emission Vapor
P = Air Emission Particulate

FIGURE 3-5

WOVEN FABRIC FINISHING MILL

a commission basis and, therefore, have no process water requirements. In those isolated instances where sweater or similar mills dye their own yarn, these mills are included under the Stock and Yarn Dyeing and Finishing Mill category.

The knit fabric segment of the industry has about 540 plants. These plants are the source of finished knit piece or yarn goods for the apparel, industrial, and household goods trades, and also serve to augment supplies of fabric to underwear and outerwear manufacturers. These plants are the main subject of this category. The large knit fabric plants are located mainly in North and South Carolina and Georgia, but substantial numbers are also located in New York and Pennsylvania.

The main difference between woven and knit fabric finishing is that the sizing/desizing and mercerizing operations are not required for knits; therefore, raw waste load levels are lower.

The wet processing operations performed in knit fabric finishing are shown schematically in Figure 3-6. This is necessarily a generalized flow sheet; the specific operations employed in a given plant will vary from plant to plant. In general, the yarns are purchased in the undyed state, with a knitting oil finish to provide lubrication for the knitting operation. After the yarn has been knitted into fabric, the fabric may be processed by one or more of the alternative routes indicated. The wet process operations employed in a plant depend on the nature of the goods involved and the end product requirements.

3.2.6 Carpet Mill

Carpet mills form a distinct part of the industry although their effluents are similar in many ways to those of the Knit Fabric Finishing Mill. Carpet mills use mostly synthetic fibers (nylon, acrylics and polyesters), but some wool and some cotton are processed. The carpet mill category is characterized by any or all of the following unit operations: bleaching, scouring, carbonizing, dyeing, printing, resin treatment, water proofing, flame proofing, soil repellency, backing with foamed and unfoamed latex and jute. Carpet backing without other carpet manufacturing operations is included in the Dry Processing Mill category. Although some carpet is backed with latex in a separate plant, some carpet mills do latexing in the same plant with the finishing.

Tufted carpets account for well over 65% of the plants and 85% of the dollar value; they constitute 74% of the employment in this industry (2). Therefore, this section is written principally around this segment. Tufted carpets consist of face yarn that is looped through a woven mat backing (mostly polypropylene, some jute), dyed or printed, and then backed with either latex foam or coated with latex and a burlap-type woven fabric backing put over the latex.

The dominant face yarn is nylon, followed by acrylic and modacrylic, and polyester; the latter two groups in total are about equal to nylon. Since dyeing of these fibers in carpets differs little

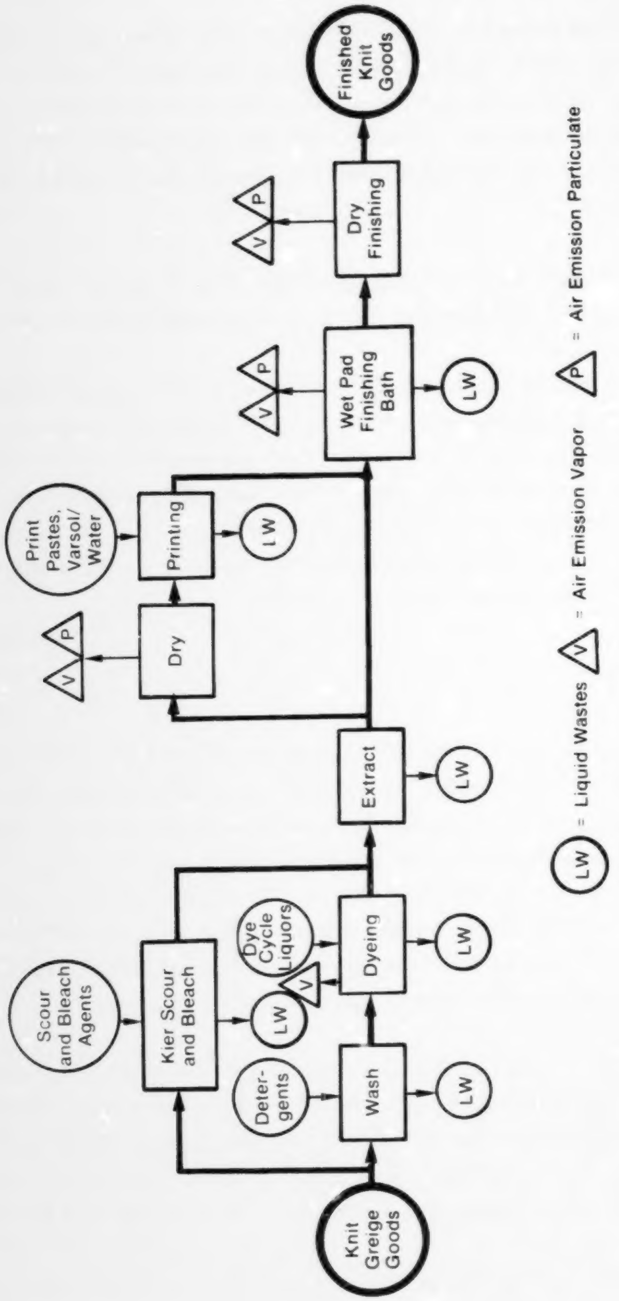
Knit Greige Goods
Deter-gents
Wash
LW
Scour and Bleach Agents
Kier Scour and Bleach
LW
V
Dye Cycle Liquors
Dyeing
LW
Extract
LW
Dry
V
P
Print Pastes, Varsol/Water
Printing
LW
Wet Pad Finishing Bath
V
P
LW
Dry Finishing
V
P
Finished Knit Goods
LW = Liquid Wastes
V = Air Emission Vapor
P = Air Emission Particulate

FIGURE 3-6

KNIT FABRIC FINISHING MILL

from dyeing fabric, the dyeing descriptions for these fibers given in other categories applies hereto.

Carpets may be yarn dyed, piece dyed, or printed. When yarn dyed carpets are made, the yarn is often dyed in another mill and brought to the carpet mill. The relative quantities of yarn, beck, and continuous dyeing, and printing and latexing may vary widely.

The yarn is tufted into a woven or synthetic nonwoven polypropylene or jute primary backing in a dry operation (Figure 3-7). Following this, the tufted carpet can be either printed or dyed. If printed, a semi-continuous screen printing operation is performed, followed by a wash and rinse step in the same machine. If dyed, the most common method is beck dyeing, in a manner quite similar to that described in previous categories for yard goods. The industry claims a higher liquor-to-fabric ratio, however, because of the difficulty in making the carpet sink and become thoroughly wetted. Many small air bubbles become entrapped in the tufts. The continuous dyeing appears very similar to the continuous pad-stream process used for cotton/synthetic blends broadwoven finishing. After it is dyed the carpet is dried in a tunnel drier. The carpet is then ready for application of adhesive and a secondary backing.

3.2.7 Stock and Yarn Dyeing and Finishing Mill

Yarn dyeing and finishing are different from woven fabric finishing because there is no sizing and desizing operation. They are different from knit fabric finishing because of their mercerizing operations and water use. These differences alone are sufficient to justify a separate category. Further justifying a separate category is the fact that the waste loads from this type of plant can vary more than those from other types of integrated textile mills or finishing mills. This category is typically characterized by any or all of the following unit operations: cleaning, scouring, bleaching, mercerizing, dyeing and special finishing.

This category includes plants which clean, dye and finish fiber stock or yarn. Sewing thread, textile and carpet yarn are typical products. In this category crude yarn may be obtained from a spinning facility or it may be spun in the plant. The yarn may be natural, synthetic or blended.

Several techniques are available for processing raw yarn into the finished product. The most common process is probably package dyeing, but other processes, such as space dyeing, are widely used. In the former process, yarn wound on perforated tubes is placed in a large vessel, which is sealed. The dye solution, at an appropriate temperature, is circulated through the yarn. The dyed yarn is washed, rinsed and dried. In space dyeing, yarn is knitted and the fabric is dyed or printed, washed, rinsed and dried. The fabric is then unravelled and the yarn is wound on cones for subsequent use by other mills. Figure 3-8 represents typical operation of a Stock and Yarn Dyeing and Finishing Mill.

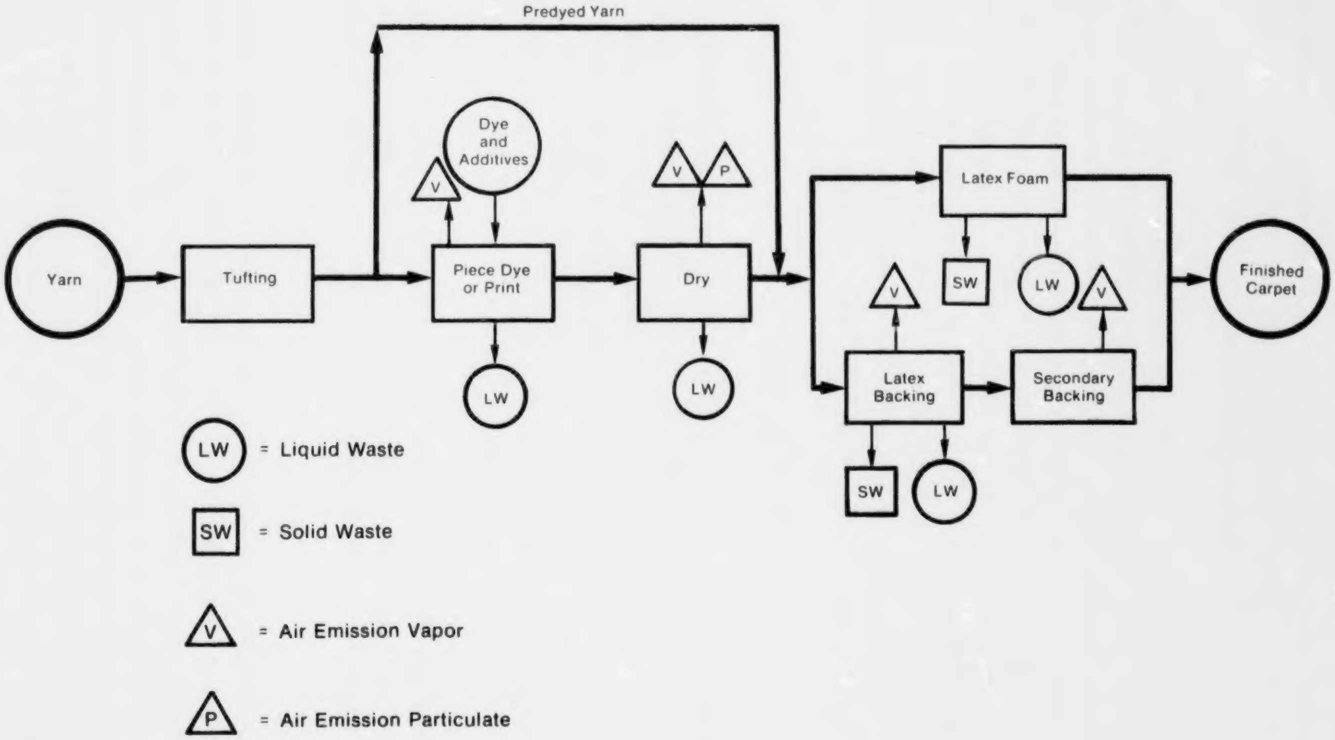
Predyed Yarn
Yarn
Tufting
Dye and Additives
V
Piece Dye or Print
LW
V
P
Dry
LW
Latex Foam
SW
LW
V
Latex Backing
SW
LW
V
Secondary Backing
Finished Carpet
LW = Liquid Waste
SW = Solid Waste
V = Air Emission Vapor
P = Air Emission Particulate

FIGURE 3-7

CARPET MILL

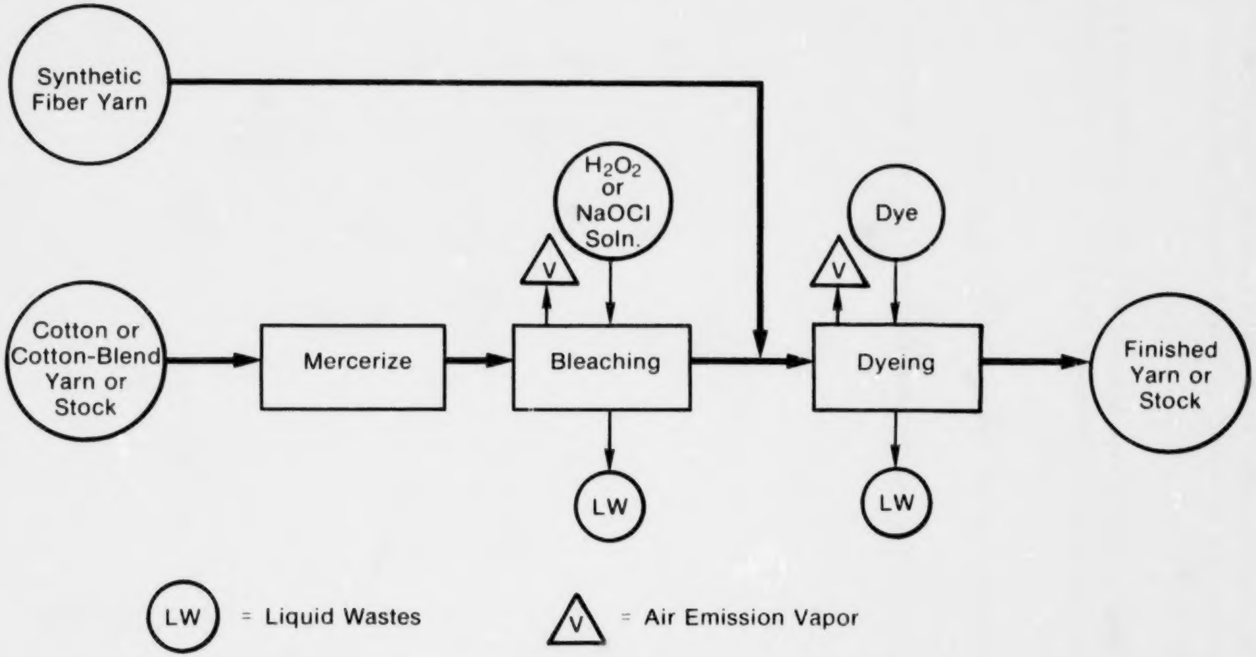
Synthetic Fiber Yarn
Cotton or Cotton-Blend Yarn or Stock
Mercerize
H_2O_2 or NaOCl Soln.
V
Bleaching
LW
Dye
V
Dyeing
LW
Finished Yarn or Stock
LW = Liquid Wastes
V = Air Emission Vapor

FIGURE 3-8

STOCK AND YARN DYEING AND FINISHING MILL

3.3 References

1. Institute of Textile Technology and Hydroscience, Inc., *Recommendations and Comments For The Establishment of Best Practicable Waste Water Control Technology Currently Available For The Textile Industry*, for American Textile Manufacturers Institute, Inc. and The Carpet and Rug Institute, 1973.

2. U.S. Environmental Protection Agency, *Development Document for Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Textile Mills Point Source Category*, June 1974.

American Textile Manufacturers Institute, *Textile Hi-Lights*, June 1974.

USDA, Economic and Statistical Analysis Division, Economic Research Service.

CHAPTER 4

SOURCES AND STRENGTHS OF TEXTILE WASTEWATER

4.1 Introduction

Textile mill operations include a number of wet and dry processes, each of which may require several mechanical manipulations. As a general rule, however, the majority of all aqueous waste from the textile industry can be described in four separate categories (1):

1. Scouring
2. Bleaching
3. Dyeing or Printing
4. Special Finishing

Special finishing is meant to include all wastes which cannot be included in the first three categories.

Textile wastes are generally gray in color, or the color of the predominant dye being used, high in BOD and total dissolved solids, highly alkaline and high in temperature. The wastes usually exhibit extreme variability in strength and flow and also may at times contain toxic compounds. The sources of pollution are the natural impurities extracted from the fiber and the chemicals used in processing the fiber. The basic factors which determine the characteristics of the wastewater quantity and quality are therefore: 1) the type of fiber being processed; 2) the unit operations comprising the overall textile process; 3) the chemicals used in the process; and 4) the degree of "in-house" conservation measures being practiced (2).

Cotton and synthetic fibers are generally woven into cloth before any finishing operations are applied. Wool is generally washed (scoured) and dyed before being woven into cloth. In either case, weaving contributes indirectly to the wasteload by the addition of sizes and anti-static lubricants.

4.1.1 Scouring

Desizing and scouring of natural fibers – cotton and wool – removes natural impurities such as dirt and grease as well as the chemical additives mentioned above. In the wool industry, scouring removes impurities approximately equal in weight to the residual fiber weight, creating one of the strongest liquid wastes, in terms of BOD, of any industry (1). Synthetic fiber scouring wastes, on the other hand, are relatively low in both pollution and volume due to the lack of natural impurities and the small amounts of additives used. The cotton finishing industry also commonly desizes woven cloth for starch removal followed by a thorough scouring, for the removal of impurities.

In both the cotton and wool industries, scouring and washing is the major source of pollution, contributing over half of the total plant BOD and solids (1). In the synthetic textile industry, scouring and washing are not major contributors to the wastestreams, generally producing less than half of the total plant pollution measured as BOD.

4.1.2 Bleaching

Bleaching is generally accomplished by soaking the cloth in a standing bath containing an oxidizing agent in solution, or in a continuous bleaching process. Nearly all of the cotton produced is bleached, regardless of its final color, using hypochlorite or hydrogen peroxide. Wool is commonly bleached with hydrogen peroxide and acid. Synthetics are bleached with hydrogen peroxide, sodium hypochlorite, peracetic acid, sodium chlorite, or other chemicals.

Only a small percentage of wool and synthetic cloth is bleached white. Natural wool is yellow in color and bleaching is required only when white of light colors are desired. Synthetic cloth is bleached for the removal of stains or when a translucent bluish-white color is desired.

Bleach wastes may be toxic and acidic but are not high in organic pollutant concentration and generally do not contribute more than 5% of the plant's organic wasteload (1).

4.1.3 Dyeing and Printing

The types of dyes commonly employed by the textile industry include direct, disperse, acid and pre-metalized, vat, basic, sulphur, fiber reactive, napthol and azoic. Of these, the first six account for approximately 85% of the total used. The quantity of dye used depends on the characteristics of the fiber, the color, and the desired finish. Some synthetic textiles require the use of special carriers to achieve satisfactory penetration of the dye into the fiber. These carriers are very strong and present a major source of pollution in the finishing of synthetic fibers. It has been estimated that greater than 90% of the dye processed is exhausted onto the fabric and the remaining 10% or less is rinsed to waste. In some cases, pressure dyeing at high temperatures is an alternative method to the use of carriers in dyeing. This method avoids both the cost and pollution of carrier dyeing while allowing satisfactory dye penetration in a shorter period of time.

Printing is most often done by roller application of various dye pastes. Chemical treatment follows printing to fix the color, and a final wash and rinse is employed to remove any residue. Printing process waste usually does not contribute significantly to the total waste load. The pollution load from the dyeing and printing sub-processes is approximately 3 to 10% of total plant BOD and solids in the wool industry. In cotton finishing the range is 15 to 35%, and for synthetics it is 5 to 80% (1).

4.1.4 Special Finishes

Special finishes include waterproofing, moth-proofing, fireproofing, pre-shrinking, brightening, durable press, etc. In addition, wool is fulled to achieve a felt-like appearance and cotton may be mercerized or causticized to smooth its surface. Most of these special finishing processes involve chemical treatment and removal of residue by washing and/or rinsing. The pollution contribution of special finishing sub-processes is in the range of 5 to 15% of the plant total (1).

4.1.5 Summary

The wasteloads from each individual process may vary over a wide range of values due to the large number of different fibers produced, each having its own distinctive characteristics. However, variations also exist between different plants processing the same fiber, due to technological differences in production procedures and many other variables which may exist. Additionally, many of the nation's textile mills are involved in the production of cloth composed of a combination of fibers requiring a variable process methodology dependent on cloth composition. Although quantities may vary, the wasteload characteristics are generally similar for all textile mills processing the same fiber.

Wool waste waters are characterized by high BOD, high solids concentration, and high grease content. Dye waste waters contain color which is extremely difficult to remove by common waste treatment methods. Wool grease presents an especially difficult problem because pretreatment for removal may be necessary before efficient biological treatment of the plant effluent is feasible. Cotton finishing wastes are not nearly as strong as those produced by the wool industry, having no grease and a relatively low solids content. Other characteristics are high BOD (although considerably lower than that found in wool wastes) and possible high color content. Synthetic finishing wastes are generally lower than cotton finishing wastes in pollutant quantities and characteristics. One significant difference can be the toxicity of synthetic dye wastes when metallic ion content dyes are used. Pollutant quantities per 1000 pounds of finished cloth vary over a wide range of values due to the many different types of fibers processed (1). Toxicity of synthetic fiber dye wastes can retard or prevent biological waste treatment when concentrations are significant. In such cases chemical pretreatment will be required prior to biological treatment or discharge to municipal sewers.

Water usage in the textile industries is relatively high due to the large amounts of water required in washing and rinsing operations. Cotton and wool finishing mills use 30,000 to 70,000 gallons of water per 1000 pounds of cloth. Synthetic finishing mills use considerably less water, ranging from 3000 to 29,000 gal/1000 pounds cloth (1). This lower water requirement reflects the lack of natural impurities on synthetic fibers, allowing less thorough washing as compared to cotton or wool. Water reuse has not been practiced to a great extent; however, it is expected that greater recirculation practices will be adopted in the future as water costs and pressures from regulatory agencies increase.

Wastewater characteristics have been tabulated by fiber processed for each pollutant parameter. Each table lists unit processes, waste generating sources, wastewater concentrations (in mg/l and lb/1000 lb product) and water use in gallons/1000 lb product. These tables can be found at the end of each processed fiber section as follows:

Section 4.2 – Cotton – Table 4-2 thru Table 4-9
Section 4.3 – Wool – Table 4-10 thru Table 4-14
Section 4.4 – Synthetic – Table 4-15 thru Table 4-29
Section 4.5 – Synthetic Blends – Table 4-30 and Table 4-31

4.2 Cotton Processing

The basic cotton fabric manufacturing processes which produce aqueous waste are:

- Slashing
- Desizing
- Scouring
- Mercerizing
- Bleaching
- Dyeing and Printing
- Finishing

4.2.1 Slashing

Slashing is the first process during weaving in which liquid treatment is involved. In slashing, the warp threads are coated with size (either starch or synthetic) to facilitate weaving by giving the threads tensile strength and smoothness. The compound is then dried on the threads and remains a part of the cloth until it is removed in subsequent processes. Although the slashing (sizing) compounds used most often are natural starches, other compounds such as polyvinyl alcohol (PVA), resins, alkali-soluble cellulose derivatives, gelatin glue, locust bean gum and gum tragacanth have been used. One of these, sodium carboxy-methyl-cellulose, or CMC, is finding some acceptance, mostly in the sizing of polyester blends. Other chemicals, such as lubricants, softeners, emulsifiers, humectants, preservatives ($ZnCl_2$, phenol, etc.), penetrants, anti-foam agents, and fillers, are often added to impart additional properties to a fabric. The grey goods thus prepared usually contain about 10 to 15% add-on, mostly sizing (1).

Liquid waste from slashing operations results from cleaning the slasher boxes, rolls and makeup kettles. Some spillage also occurs; however, the volume is usually low. Some textile greige mills produce a wide variety of woven goods, each requiring a specially formulated size. In mills of this type the size boxes may be dumped and cleaned several times a day depending upon the production schedule. In unusual cases such as this, slashing operations may produce a great volume of waste. Although the BOD of slashing waste can be quite high (to 810,000 mg/l for corn starch), slashing operations normally contribute only 5% BOD and 4.5% total solids to the total plant waste load.

Wastewaters from slashing operations are characterized by the following range of pollutants generated: BOD – 620 to 2500 mg/1, TS – 8500 to 22,600 mg/1, pH – 7 to 9.5 units, and water use – 60 to 940 gal/1000 lb. product.

Slashing wastewater is the first heavily contaminated liquid that is discharged during the fabric production process.

4.2.2 Desizing

The operation of desizing removes the sizing compound that was applied to the threads in the slashing operation, as well as mildewcides and fungicides and other impurities. The most common desizing operations are acid desizing and enzyme desizing (3).

The acid desizing process utilizes a solution of dilute sulfuric acid to hydrolyze the starch and render it water soluble, whereas the enzyme desizing process utilizes vegetable or animal enzymes to decompose starches to a water soluble form. In either case, the desizing mixture is normally applied to the fabric by means of a padder with a paper roll covering and pressure to insure that the fabric will be well saturated.

In acid desizing, the fabric soaks in a solution of sulfuric acid, at room temperature, for a period of 4 to 12 hours and is then washed (4). In enzyme desizing, the fabric and solution are maintained at a temperature of 130 to 180° F and a pH of 6 to 7.7 for a period of 4 to 8 hours (5). After the size has been solubilized, the fabric is rinsed clean. For desizing of polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC), materials which are directly soluble in water, no decomposition is required and the goods are merely washed with water for removal of sizing agents. This is usually done at 180° F or higher in washers without the use of steamers, J-boxes, or padders (6).

The waste from desizing operations contributes the largest BOD of all cotton finishing operations, approximately 45% (5). The waste from starch desizing is very strong with a BOD concentration as much as 5,000 ppm (7). This process also contributes the largest total suspended solids, approximately 86% of the total plant load. The rinse waters following desizing vary in strength depending on the rinsing method. Desizing of synthetic size (CMC, PVA) results in greatly reduced BOD load.

Depending upon size material to be removed in the desize operation, the waste characteristics will have the following range: BOD – 200 to 5200 mg/1, TS – 3800 to 3200 mg/1, pH – 6 to 8 units, and water use – 300 to 2500 gal/1000 lb. product.

4.2.3 Scouring

Scouring is a process in which the natural impurities (wax, pectins, alcohols, etc.), as well as the processing impurities (size, dirt, oil and grease, etc.) are removed from the fabric by hot alkaline detergents or soap solutions. Scouring is also used to make the fibers in the cloth whiter and more absorbent for subsequent bleaching and dyeing.

Scouring is accomplished by one of two methods, kier boiling or open width scouring, depending on the characteristics of the fabric. Kier boiling is often employed for scouring desized cotton fabrics wherein the fabric (in rope form) is contained in a large vertical pressure vessel. In this process, the scouring chemicals are recirculated through the goods with heat supplied by an external heat exchanger. Open width scouring is used on certain heavy weight fabrics not normally processed in rope form.

Open width goods are processed in an open width boil-out machine, also known as the progressive jig. The jig is loaded with a scouring solution and the goods are fed continuously through by the use of eight or ten transfer rolls. The system is heated with steam coils and the temperature and residence time are maintained for proper scouring of the goods. The goods are wound onto rolls in the machine and maintained in contact with scouring liquids for the necessary period. Then they are unrolled through wash boxes and folded into a cloth truck or onto a roll.

Caustic soda (NaOH) and soda ash (Na_2CO_3) are used in most scouring operations, the former in concentrations of 1 to 8% of the cloth weight, the latter only 1 to 3% on weight of fibers. Sodium silicate (Na_2SiO_3) is generally used in smaller doses (0.25 to 1% on weight of fiber) (1). Pine oil soap to remove wax, and fatty alcohol sulfates to aid in melting, are also sometimes used in scouring. Although the fresh scour solution is clear, after scouring under pressure (5 to 15 psi) and at elevated temperature (200° F) for 2 to 12 hours, the scour liquid is an opaque brown (1). Methods of scouring and dumping of the scour waste vary from mill to mill; however, in all mills the cloth is rinsed completely until no brown color is left in the rinse water.

Scour liquor waste contributes approximately 16% of the total plant BOD. The grease and oil contribution is approximately 67% of the total. This is due to natural wax, oil and dirt present in cotton.

Wastewater characteristics for scour liquor are within the following range: BOD – 100 to 2900 mg/1, TS – 2200 to 17,400 mg/1, pH – 10 to 13 units, temperature – 250° F, and water use – 300 to 5100 gal/1000 lb. product.

4.2.4 Mercerizing

The process results in increased tensile strength, increased surface luster, increased abrasion resistance, reduction in potential shrinkage and increased affinity for dyestuffs.

Mercerization is accomplished by saturating the fabric with cold NaOH (15 to 30%). Physically, mercerization causes swelling of the cellulose fibers as alkali is absorbed into them, with higher concentrations, longer residence times, and lower temperatures favoring greater swelling. Mercerization may be conducted on greige goods (after desizing), on scoured goods (after kier boiling or caustic treatment) or on bleached goods. More complete mercerization results from treatment of bleached fabrics (in terms of fiber swelling), but mercerization of greige goods or scoured goods results in greater tensile strengths.

After the desired period of contact, the caustic is thoroughly washed off, sometimes with the aid of an intermediate acid wash. Generally, the caustic soda dragged out by the cloth is recovered and reused for scouring or mercerization. The mercerizing rinse wastes are alkaline, high in inorganic solids and caustic alkalinity, and low in BOD. With the increasing trend toward cotton-polyester blends, much less mercerizing is being done. It is estimated that less than 30% of cotton is now mercerized or causticized.

Mercerizing wastewater characteristics are dependent upon the degree of caustic recovery practiced in the mill and generally range as follows: BOD – 50 to 800 mg/1, TS – 320 to 18,000 mg/1, pH – 5.5 to 14 units, and water use – 2,000 to 37,000 gal/1,000 lb. product.

4.2.5 Bleaching

Bleaching of cotton cloth may be done with oxidizing agents, but sodium hypochlorite, sodium chlorite and hydrogen peroxide are the most common. Bleaching may be carried out immediately after scouring or after mercerizing, and may be done in bins, jigs or on a continuous basis.

In sodium hypochlorite bleaching, the cloth is first rinsed, scoured with a weak solution of sulfuric or hydrochloric acid and rinsed again. The cloth is then passed through a solution of sodium hypochlorite (about 0.25 to 0.50% available chlorine) and piled into large concrete bins or fed into a J-box if continuous operation is desired. The time required for hypochlorite bleaching varies with the type of cloth and may take from a few hours to as long as 24 hours at room temperature (1). The rinses following sodium hypochlorite bleaching are usually neutral in pH, vary in BOD depending upon the impurities in the fiber, and contain considerable amounts of free chlorine. A final rinse, which may contain an antichlor such as sodium bisulfite or sulfuric acid, is used to remove residual chlorine from the fabric. When bleaching with sodium chlorite, acetic acid is used in place of sulfuric or hydrochloric acid, the temperature of the bath is hot (108 to 185° F), and the pH is 3.5 to 5.5 (3).

Hydrogen peroxide is generally used for bleaching in the continuous process. Continuous bleaching ranges are employed for processing the majority of the cotton and cotton blended fabrics today. Fabric is fed in either rope or open width form and, in certain cases, the desizing, scouring and mercerizing operations are placed in tandem with the continuous bleaching range. The continuous bleaching process begins with a hot water (140 to 175° F) wash to insure removal of all contaminants. As the goods leave the washer excess water is removed and sodium hydroxide is added. The saturated material remains at 175 to 180° F for approximately 40 minutes to one hour resulting in the conversion of fats and waxes to soaps. The material is then rinsed, passed through a peroxide solution and allowed to bleach out at a temperature of 195° F for approximately 40 minutes to one hour (3).

The bleaching process contributes the lowest BOD to the total plant load. Wastewaters are characterized by the following ranges: BOD – 100 to 1,700 mg/1, TS – 840 to 14,400 mg/1, pH – 8.5 to 12 units, and water use – 300 to 14,900 gal/1,000 lb. product.

4.2.6 Dyeing and Printing

Dyeing is the process of applying color to the fiber stock, yarn or fabric. There are various methods of dyeing and many more types of dyes for each method. There are, however, six main classes of dyes for cotton fabric: vat, direct, developed, naphthol, sulfur and aniline black.

Vat dyes, known as fast dyes, are insoluble in water. They actually bond-in the colorant and are the most resistant of any types to light, dry cleaning, sunlight and washing. In the vat dyeing process, the insoluble dye is first made soluble in water by use of reducing chemicals and is then applied to the fibers. The absorbed dyestuff is then reoxidized to its insoluble highly colored form. An acid rinse (usually acetic acid) is used to neutralize the alkali present in the dye bath followed by detergent washing to produce brightness and wash resistance. Vat dyeing may be accomplished in individual batches or in continuous dye ranges.

Direct dyes are so named because they may be applied to the fibers without pre-application of chemicals required for retention. The advantages of direct dyes are their ease of application, low cost and variety of shades while the disadvantages are poor light and wash resistance, and poor resistance to acids and alkalis. Direct dyeing may be accomplished in dye becks, dyeing jigs, dye ranges and package dyeing units. Direct dyes may be applied with or without heat but with higher dye utilization at higher temperatures. Some direct dyes are subjected to post treatment with copper sulfate and acetic acid to increase light fastness and with potassium dichromate and acetic acid or formaldehyde to increase wash fastness.

Developed dyeing is a procedure wherein two different chemicals are employed. The first chemical (½ to 4% dye) is applied and absorbed into the fibers (1). The second chemical (developer) is then applied and a reaction with the first takes place directly on the fiber for stable color development. Dyeing is followed by rinsing to complete this process. The major advantage of developed dyeing is the production of a dyed fabric which possesses greater wash fastness. However, it may not have good light resistance.

Naphthol dyeing is developed dyeing in reverse. The cloth is first impregnated with the developer and then the dye is formed on the fiber by saturation in the dye bath. The advantages of naphthol dyes are good fastness and economy. Their major disadvantage is a limited range of colors.

In the actual process, the naphthol dye is dissolved by mixing with either sodium hydroxide under heat or ethyl alcohol and a cold solution of sodium hydroxide. The dissolved naphthol dyestuff is then added to the dye bath where the goods are dyed from 20 to 40 minutes at 80 to 100° F (6).

The naphthol is then ready for development in which it is coupled to the other portion of the final dye molecule. The so-called "fast color bases" are compounds with a free amino acid group which may be diazotized so that they will react with the naphthol. The base is placed in a solution to which sodium nitrite and hydrochloric acid have been added. Temperature is maintained at or below 40° F and the chemical reactions are similar to those employed in developed dyeing. Sodium acetate is employed to neutralize excess chemicals which would hinder the coupling reaction; acetic acid is used to neutralize excess alkali.

The naphtholated goods are then treated with a diazotized base for 20 to 30 minutes within the dye bath at room temperature. This coupling reaction can also be done in a dye box or on a continuous dyeing range (6).

Finally, the goods are detergent washed and rinsed, using a soap solution containing soda ash for 15 minutes at up to 200° F. The surface dye is removed, the shade is developed and fastness is improved.

Sulphur dyes are principally used to dye heavy cottons in shades of blacks, dark blues, browns, and other dark colors. The dyes are generally water insoluble and require dissolving in an alkaline solution before application. The dye is usually applied at high temperatures (140 to 212° F) using salt as an exhausting agent (6). Reoxidation is commonly done with sodium dichromate, acetic acid, sodium perborate or hydrogen peroxide. After dye reoxidation, surplus dyestuffs are removed by thorough washing with detergents.

Aniline black dye is an insoluble pigment produced by the oxidation of aniline. The cloth is passed through a dye bath typically consisting of 90 pounds of aniline hydrochloride, 35 pounds of sodium chlorate, and 13 pounds of $CuSO_4$ in 100 gallons of water (1). After impregnation, the cloth is given a steam treatment to develop the black pigment. Alkaline sodium dichromate treatment completes the process. Since the dye bath is not exhausted, it is seldom dumped.

Dyehouse wastewaters may contain quantities of chromium if aniline or sulfur dyeing methods are used. BOD generated from process chemicals used account for approximately 18% of the total plant load. Total dissolved solids contributed by dyeing account for approximately 34% of the total plant load. The high color values of the plant wastes are attributed to this operation. Table 4-1 presents a list of cotton and wool dyes, and chemicals used in the dyebaths.

Depending upon dye types and dyeing methods the wastewater characteristics are in the following ranges: BOD – 60 to 600 mg/1, TDS – 600 to 5,400 mg/1, Cr – 40 to 168 mg/1, pH – 6 to 12 units, and water use – 5,000 to 30,000 gal/1,000 lb. product.

TABLE 4-1

CHEMICALS PRESENT IN COTTON AND WOOL DYEBATHS

Dye Type	*Chemicals Present*
	Cotton
Aniline Black	Aniline hydrochloride, sodium ferrocyanide, sodium chlorate, pigment, soap, sodium di-chromate.
Developed	Dye, penetrant, sodium chloride, sodium nitrite, hydrochloric acid or sulfuric acid, developer (beta naphthol), soap or sulfated soap or fatty alcohol.
Direct	Dye, sodium carbonate, sodium chloride, hydrochloric acid, wetting agent or soluble oil or sodium sulfate.
Naphthol	Dye, caustic soda, soluble oil alcohol, soap, soda ash, sodium chloride, base, sodium nitrate, sodium nitrite, sodium acetate.
Sulfur	Dye, sodium sulfide, sodium carbonate, sodium chloride, sodium di-chromate, hydrogen peroxide.
Vat	Dye, caustic soda, sodium hydrosulfite, soluble oil, gelatin, perborate or hydrogen peroxide.
	Wool
Acid	Dye, sulfuric or acetic acid or ammonium sulfate and Glauber Salt.
Metalized	Dye, acetic or sulfuric acid or ammonium sulfate.
Mordant	Acetic acid, sodium sulfate, sodium di-chromate.

Source: Reference 3

Colored patterns on cloth are usually printed. In roller printing, the cloth is rolled around a large central cylinder on top of a "dark" cloth used to absorb any printing paste which may seep through. Copper rolls with engraved designs on the circumference of the cylinder are padded with dye paste (from close-by color boxes). These rolls, wiped free of excess paste by a "doctor" blade, pass tightly against the cloth. Dye paste in the engraved depressions is imprinted on the cloth. Steaming or aging treatments finally fix the color prior to washing, rinsing, drying and finishing. Pollution from color shops (where printing is usually done) comes mainly from the washing tubs, dippers, cloths, drums, and any equipment used to make and carry the printing pastes. Washing the printed cloth also contributes to pollution.

Printing wastes can contain high concentrations of BOD and dissolved solids. Printing pigments will also introduce suspended solids into the waste stream.

Wastewater characteristics are defined as the following ranges: BOD – 100 to 650 mg/1, TSS – 10 to 750 mg/1. TDS – 200 to 1000 mg/1, pH – 6 to 11 units, and water use – 1500 to 4000 gal/1000 lb. product.

4.2.7 Finishing

Finishing is a general term which covers the treatment of a fabric to give it a desired surface effect such as calendered, embossed, lacquered, napped, etc. Special finishes can be applied to make a fabric crease resistant, crease retentive, waterproof, etc. Starch, dextrin, wax, tallow, oil, clay, talc, and other weighting compounds are typical finishing compounds. In recent years, resins, cellulosic solutions, lacquers, sulfonated compounds, and quaternary ammonium salts have been used. Other finishing processes, such as leveling off (hot detergents) to produce a uniform appearance, softening (hot soap) to produce a soft feel, and rust stain removal (oxalic acid and sodium acid fluoride) to improve color are also sometimes used.

Finishing wastewaters are low in BOD and wastewater volume produced and can be characterized by the following ranges: BOD – 20 to 500 mg/1, TS – 40 to 2340 mg/1, pH – 6 to 8 units, and water use – 1,500 gal/1,000 lb. product.

TABLE 4-2
BOD CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	BOD SOURCES	BOD LB./1000 LB. PRODUCT	BOD mg/l	WATER USE GALLONS/1000 LB. PRODUCT	REFERENCE
SLASHING:	Natural Starches, resins	0.5 – 5.0	(620 – 2,500)	60-940	7
DESIZING:					
Enzyme Starch	Glucose from Starch	45.6	(3,645)	1,500	6
Acid Starch	Glucose from Starch	45.6	(3,645)	1,500	6
Polyvinyl Alcohol	Soluble Polyvinyl Alcohol	2.5	(200)	1,500	6
Carboxymethyl	Soluble Carboxymethyl	3.93	(314)	1,500	6
Cellulose	Cellulose	—	—	—	—
SCOURING:					
Unmercerized Greige Fabric	Natural Waxes, Pectins, Alcohol, Etc.	21.4	(855)	3,000	6
Mercerized Greige Fabric		16.4	(655)	3,000	6
MERCERIZING:					
Greige Fabric	Penetrants such as NaOH	12.9	(773)	2,000	6
Scoured Fabric		4.0	(240)	2,000	6
Bleached Fabric		1.66	(100)	2,000	6
BLEACHING:					
Hydrogen Peroxide (Woven Goods)	Penetrants	1.4	(84)	2,000	6
Hydrogen Peroxide (Knit Goods)		23.5	(282)	10,000	6
Sodium Hypochlorite (Woven Goods)		0.08	(5)	2,000	6
DYEING:					
Direct (Woven Goods)	Sodium Sulfate, Soluble Oil	2.59	(62)	5,000	6
Direct (Knit Goods)	Wetting Agent, Etc.	21.1	(84)	30,000	6
Developed (Woven Goods)	Penetrant, Sodium Nitrate, Developer, Soap, Etc.	5.22	(125)	5,000	6
Developed (Knit Goods)		26.8	(107)	30,000	6
Vat (Woven Goods)	Sodium Hydrosulfite, Soluble Oil, Gelatine, Etc.	19.1	(458)	5,000	6
Vat (Knit Goods)		42.4	(169)	30,000	6
Sulfur (Woven Goods)	Sodium Sulfide, Sodium Carbonate	24.0	(576)	5,000	6
Sulfur (Knit Goods)		42.4	(169)	30,000	6
Naphthol (Woven Goods)	Sodium Acetate, Soluble Oil, Soap, Etc.	5.4	(129)	5,000	6
Naphthol (Knit Goods)		30.6	(122)	30,000	6
Fiber Reactive (Woven Goods)	Sodium Ferrocyanide, Sodium Chlorite, Pigment	5.8	(139)	5,000	6
Fiber Reactive (Knit Goods)		26.6	(106)	30,000	6
PRINTING:					
Pigment (Woven Goods)	Starch, Glycerol, Reducing Agent, Detergents, Soaps, Etc.	1.3	(101)	1,500	6
Pigment (Knit Goods)		1.3	(101)	1,500	6
Vat Dye (Woven Goods)		21.5	(644)	4,000	6
Vat Dye (Knit Goods)		21.5	(644)	4,000	6
FINISHING:					
Starch	Glucose, Cellulosic Solutions, Sulfonated compounds, Detergents, Soaps, Etc.	2.3	(184)	1,500	6
Resin		0.7	(56)	1,500	6
Resin Finishing & Flat Curing		6.3	(505)	1,500	6
Softener		0.25	(20)	1,500	6

TABLE 4-3

TOTAL SUSPENDED SOLIDS (TSS) CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	BOD SOURCES	TOXIC MATERIAL		WATER USE	REFERENCE
		LB./1000 LB. PRODUCT	mg/l	GALLONS/1000 LB. PRODUCT	
SLASHING:	—	—		60 - 940	7
DESIZING:					
Enzyme Starch	Substance Removed from the Yarn Applied in the Slashing Operation	89	(7,114)	1,500	6
Acid Starch		89.5	(7,154)	1,500	6
Polyvinyl Alcohol		5.0	(400)	1,500	6
Carboxymethyl Cellulose		5.0	(400)	1,500	6
SCOURING:					
Unmercerized Greige Fabric	Cotton, Wax, Non-Cellulosic Components of the Cotton	5.0	(200)	3,000	6
Mercerized Greige Fabric		5.0	(200)	3,000	6
MERCERIZING:					
Greige Fabric	Natural Impurities from Rinsed Water	5.0	(300)	2,000	6
Scoured Fabric		5.0	(300)	2,000	6
Bleached Fabric		5.0	(300)	2,000	6
BLEACHING:					
Hydrogen Peroxide (Woven Goods)	Residual from Rinsed Water	4.0	(240)	2,000	6
Hydrogen Peroxide (Knit Goods)	Impurities in the Fiber	—		10,000	6
Sodium Hypochlorite (Woven Goods)		4.0	(240)	2,000	6
DYEING:	No TSS	—		5,000 - 30,000	6
PRINTING:					
Pigment (Woven Goods)	Printing Paste, Thickener	0.13	(10)	1,500	6
Pigment (Knit Goods)	Rinsed Water Used for Cleaning Equipment	0.13	(10)	1,500	6
Vat Dye (Woven Goods)		25.0	(749)	4,000	6
Vat Dye (Knit Goods)		25.0	(749)	4,000	6
FINISHING:					
Starch		—		1,500	6
Resin		—		1,500	6
Resin Finishing & Flat Curing	Resin, Wax, Talc.	12	(959)	1,500	6
Softener		—		1,500	6

TABLE 4-4

TOTAL DISSOLVED SOLIDS (TDS) CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	TDS SOURCES	TDS		WATER USE	REFERENCE
		LB. / 1000 LB. PRODUCT	mg/l	GALLONS / 1000 LB. PRODUCT	
		TOTAL SOLIDS			
SLASHING:	Sizing Liquid	47-67	(8,500-22,600)	60 - 940	7
DESIZING:					
Enzyme Starch	Dissolved Organic Compounds in Desizing Liquid	5.1	(408)	1,500	6
Acid Starch		7.5	(600)	1,500	6
Polyvinyl Alcohol		48.0	(3,837)	1,500	6
Carboxymethyl Cellulose		45.0	(3,597)	1,500	6
SCOURING:					
Unmercerized Greige Fabric	Soluble Impurities Removed	49.9	(1,994)	3,000	6
Mercerized Greige Fabric	By Hot Alkali and Soap Detergents	49.9	(1,994)	3,000	6
MERCERIZING:					
Greige Fabric	Dissolved Solids in NaOH and Acid Wash Rinsed Water	148	(8,873)	2,000	6
Scoured Fabric		148	(8,873)	2,000	6
Bleached Fabric		142	(8,513)	2,000	6
BLEACHING:					
Hydrogen Peroxide (Woven Goods)	Residual Chlorine from the Fabric in Rinsed Water	21.9	(1,313)	2,000	6
Hydrogen Peroxide (Knit Goods)		70.7	(838)	10,000	6
Sodium Hypochlorite (Woven Goods)		55.0	(3,297)	2,000	6
DYEING:					
Direct (Woven Goods)	Dye, Sodium Carbonate, Sodium Chloride, Wetting Agent	106	(2,542)	5,000	6
Direct (Knit Goods)		260	(1,039)	30,000	6
Developed (Woven Goods)	Dye, Penetrants, Sodium Chloride, Soap and Fatty Alcohol	225	(5,396)	5,000	6
Developed (Knit Goods)		318	(1,271)	30,000	6
Vat (Woven Goods)	Dye, Caustic Soda, Gelatine, Sodium Hydrosulfite	117-127	(2,806-3,046)	5,000	6
Vat (Knit Goods)		194	(775)	30,000	6
Sulfur (Woven Goods)	Dye, Sodium Sulfide, Sodium Chloride	154	(3,693)	5,000	6
Sulfur (Knit Goods)		193	(771)	30,000	6
Naphthol (Woven Goods)	Dye, Soda Ash, Caustic Soda, Soap, Alcohol	48.5	(1,163)	5,000	6
Naphthol (Knit Goods)		143	(572)	30,000	6
Fiber Reactive (Woven Goods)	Sodium Chloride, Pigment Soap	180	(4,317)	5,000	6
Fiber Reactive (Knit Goods)		273	(1,091)	30,000	6
PRINTING:					
Pigment (Woven Goods)	Printing Paste, Dyeing Assistant, Hydroscopic Substances and Other Chemicals	2.5	(200)	1,500	6
Pigment (Knit Goods)		2.5	(200)	1,500	6
Vat Dye (Woven Goods)		34.0	(1,019)	4,000	6
Vat Dye (Knit Goods)		34.5	(1,034)	4,000	6
FINISHING:					
Starch	Starch, Dextrin, Tallow, Lacquers, Sulfonated Compound, Ammonia Salt	4.65	(372)	1,500	6
Resin		22	(1,759)	1,500	6
Resin Finishing & Flat Curing		17.3	(1,383)	1,500	6
Softener	Hot Soap	0.5	(40)	1,500	6

TABLE 4-5

CHARACTERISTICS OF WASTEWATER BY pH FROM COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	CHARACTERISTIC	pH UNIT	WATER USE GALLONS 1000 LB. PRODUCT	REFERENCE
SLASHING:	Neutral	7.0 - 9.5	60 - 940	7
DESIZING:	Neutral Except Acid Starch Which is Low pH (1-2) Resulted From Solution of Sulfuric Acid	6 - 8	1,500	6
SCOURING:	High Alkalinity Resulted from Hot Alkaline Detergents or Soap Solutions	12.5	3,000	6
MERCERIZING:	High Alkalinity Resulted from 15 to 30 Percent Solution of Sodium Hydroxide Used in Process	12.0	2,000	6
BLEACHING:	Alkaline pH Resulted from Bleaching Solutions	9 - 12	2,000- 10,000	6
DYEING:	Neutral to Alkaline pH Resulted from Dye Used Except Developed Dyeing Which is Low pH (1-2) Due to Sulfuric Acid Solution Used in Dyeing Process	6 - 12	5,000- 30,000	6
PRINTING:	Neutral to High Alkaline	6 - 11	1,500 - 4,000	6
FINISHING:	Neutral	6 - 8	1,500	6

TABLE 4-6

COLOR CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	COLOR SOURCES	COLOR		WATER USE	REFERENCE
		$\frac{\text{LB.}}{\text{1000 LB.}}$ PRODUCT	mg/l	$\frac{\text{GALLONS}}{\text{1000 LB. PRODUCT}}$	
SLASHING:	—	—		60 - 940	7
DESIZING:	—	—		1,500	6
SCOURING:	—	—		3,000	6
BLEACHING:	—	—		2,000 - 10,000	6
DYEING:					
Direct (Woven Goods)	Dye, Chemicals, Penetrants	0.5	(12)	5,000	6
Direct (Knit Goods)	Dye, Chemicals, Penetrants	0.75	(3)	30,000	6
Developed (Woven Goods)	Dye, Chemicals, Penetrants	1.0	(24)	5,000	6
Developed (Knit Goods)	Dye, Chemicals, Penetrants	1.0	(4)	30,000	6
Vat (Woven Goods)	Dye, Chemicals, Penetrants	1.6	(38)	5,000	6
Vat (Knit Goods)	Dye, Chemicals, Penetrants	2.0	(8)	30,000	6
Sulfur (Woven Goods)	Dye, Chemicals, Penetrants	3.2	(77)	5,000	6
Sulfur (Knit Goods)	Dye, Chemicals, Penetrants	3.5	(14)	30,000	6
Naphthol (Woven Goods)	Dye, Chemicals, Penetrants	0.6	(14)	5,000	6
Naphthol (Knit Goods)	Dye, Chemicals, Penetrants	0.6	(2)	30,000	6
Fiber Reactive (Woven Goods)	Dye, Chemicals, Penetrants	0.6	(14)	5,000	6
Fiber Reactive (Knit Goods)	Dye, Chemicals, Penetrants	0.6	(2)	30,000	6
PRINTING:					
Pigment (Woven Goods)	Printing Paste, Dyeing Assistant, Chemicals	0.05	(4)	1,500	6
Pigment (Knit Goods)		—		1,500	6
Vat Dye (Woven Goods)		0.5	(15)	4,000	6
Vat Dye (Knit Goods)		0.5	(15)	4,000	6
FINISHING:	—	—		1,500	6

TABLE 4-7

OIL AND GREASE CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	OIL AND GREASE SOURCES	OIL AND GREASE LB./1000 LB. PRODUCT	OIL AND GREASE mg/l	WATER USE GALLONS/1000 LB. PRODUCT	REFERENCE
SLASHING:	—	—		60 - 940	7
DESIZING:					
Enzyme Starch	Natural Oil, Impurities from Yarn	4.8	(384)	1,500	6
Acid Starch		4.8	(384)	1,500	6
Polyvinyl Alcohol		2.4	(192)	1,500	6
Carboxymethyl Cellulose		9.4	(751)	1,500	6
SCOURING:					
Unmercerized Greige Fabric	Cotton Oil, Wax, Dirt	40	(1,599)	3,000	6
Mercerized Greige Fabric		30	(1,199)	3,000	6
MERCERIZING:					
Greige Fabric	Cotton Oil, Wax, Dirt	10	(600)	2,000	6
Scoured Fabric		—		2,000	6
Bleached Fabric		—		2,000	6
BLEACHING:	—	—		2,000 - 10,000	6
DYEING:	—	—		5,000 - 30,000	6
PRINTING:	—	—		1,500 - 4,000	6
FINISHING:	—	—		1,500	6

TABLE 4-8

TOXIC MATERIAL/DETERGENT NUTRIENT CONTRIBUTED BY COTTON FABRIC MANUFACTURING PROCESSES

PROCESS	TOXIC MATERIAL SOURCES	TOXIC MATERIAL LB./1000 LB. PRODUCT	mg/l	WATER USE GALLONS/1000 LB. PRODUCT	REFERENCE
SLASHING:	—	—		60 - 940	7
DESIZING:	—	—		1,500	6
SCOURING:					
Unmercerized Greige Fabric	Detergent, Penetrants	P = 1.04	(42)	3,000	6
Mercerized Greige Fabric		P = 1.04	(42)	3,000	6
MERCERIZING:	—	—		2,000	6
BLEACHING:					
Hydrogen Peroxide (Woven Goods)		P = 0.76	(46)	2,000	6
Hydrogen Peroxide (Knit Goods)	Bleached and Rinsed Solution	P = 2.5	(30)	10,000	6
Sodium Hypochlorite (Woven Goods)		—		2,000	6
DYEING:					
Direct (Woven Goods)	—	—		5,000	6
Direct (Knit Goods)	—	—		30,000	6
Developed (Woven Goods)	—	—		5,000	6
Developed (Knit Goods)	—	—		30,000	6
Vat (Woven Goods)	Chemicals in Dye Bath	Cr = 3.5	(84)	5,000	6
Vat (Knit Goods)	—	—		30,000	6
Sulfur (Woven Goods)	Dye, Dyeing Assistants	Cr = 7.0	(168)	5,000	6
Sulfur (Knit Goods)	Chemical	Cr = 10	(40)	30,000	6
Naphthol (Woven Goods)	—	—		5,000	6
Naphthol (Knit Goods)	—	—		30,000	6
Fiber Reactive (Woven Goods)	—	—		5,000	6
Fiber Reactive (Knit Goods)	—	—		30,000	6
PRINTING:	—	—		1,500	6
FINISHING:					
Starch	—	—		1,500	6
Resin	Resin, Cellulosic	Zn = 0.66	(53)	1,500	6
Resin Finishing & Flat Curing	Solutions, Finishing Compounds	Zn = 1.3	(104)	1,500	6
Softener	—	—		1,500	6

P = Phosphorus
Cr = Chromium
Zn = Zinc

TABLE 4-9

COMPARISON OF WASTEWATER CHARACTERISTICS FROM COTTON FABRIC MANUFACTURING PROCESSES

PROCESS/	pH, UNIT				BOD, LB/1000 LB. PRODUCT, (mg/l)				TOTAL SOLIDS, LB/1000LB. PRODUCT (mg/l)				WATER USE GALLONS/1000 LB. PRODUCT			
REFERENCES	REF 1	REF 6	REF 7	REF 8	REF 1	REF 6	REF 7	REF 8	REF 1	REF 6	REF 7	REF 8	REF 1	REF 6	REF 7	REF 8
SLASHING:	N/I	N/I	7 - 9.5	N/I	N/I	N/I	0.5 - 5.0 (620-2,500)	N/I	N/I	N/I	47 - 67 (8,500-22,600)	N/I	N/I	N/I	60 - 940	N/I
DESIZING:	6 - 8	6 - 8	N/I	6 - 8	55 (2,638)	2.5-45.6 (200-3,645)	14.1-16.1 (1,700-5,200)	N/I (3,000)	78.5 (3,765)	94.1 (7,522)	66 - 70 (16,000-32,000)	N/I (6,000)	2,500	1,500	300 - 1,100	N/I
SCOURING:	N/I	12.5	10 - 13	13	52.5 (1,399)	16.4-21.4 (650-850)	1.36-17.5 (50-2,900)	N/I (1,800)	86.6 (2,307)	54.9 (2,194)	19 - 47 (7,600-17,400	N/I (8,000)	4,500	3,000	310 - 5,100	N/I
MERCERIZING:	N/I	12	5.5-9.5	11 - 14	2.5 (75)	1.66-12.9 (100-773)	10.5-13.5 (45 - 65)	N/I (780)	10.7 (322)	152 (9,100)	185-450 (600-1,900)	N/I (8,000 - 18,000)	4,000	2,000	27,900-36,950	N/I
BLEACHING:	N/I	9 - 12	8.5-9.6	9 - 11	7.5 (200)	0.08-23.5 (5-282)	5.0-14.8 (90-1,700)	N/I (600)	40 (1,066)	26-70.7 (838-3,537)	38 - 290 (2,300-14,400)	N/I N/I	4,500	2,000-10,000	300-14,900	N/I
DYEING AND PRINTING:	N/I	1 - 12	5 - 10	4 - 8	7.5 - 30 (180-450)	1.3-42.4 (62-744)	N/I (11-1,800)	N/I (200-30,000)	11.7-47.5 (284-701)	2.63-378 (210-5,396)	25-1,200 (500-14,000)	N/I (500-40,000)	1,500-20,000	1,500-30,000	1,000-36,000	N/I
FINISHING:	N/I	6 - 8	N/I	N/I	N/I	0.25-6.32 (20-505)	N/I	N/I	N/I	0.5-29.3 (40-2,342)	N/I	N/I	N/I	1,500	N/I	N/I

NOTE: There is no information of TSS, TDS, oil and grease, color and toxic material from references 1, 7 and 8.

N/I No Information available.

4.3 Wool Processing

The five major sources of pollution which are produced during the processing of woolen fibers are:

1. Scouring
2. Washing after Fulling
3. Neutralization after Carbonizing
4. Bleaching
5. Dyeing

4.3.1 Scouring

Scouring, the first wet process wool receives, removes the natural and acquired impurities from the wool fibers. Since raw sheep wool contains from 25 to 75% suint (water soluble excretions and secretions of the sheep such as urine, feces, sweat, blood, dirt, grease, etc.), the production of one pound of scoured wool fiber also produces one and one-half pounds of waste impurities (5). Because of this, the process of wool scouring is known to have one of the strongest wastes in the textile industry.

Scouring is usually carried out in a series of 2 to 6 bowls (usually 4 bowls of 1,500 to 3,000 gallons capacity each), commonly known as a "scouring train" (1). The first two bowls of the train are filled with neutral detergents or detergents and a mild alkali such as sodium carbonate or soda ash. The third bowl is a standing rinse and the last may be either a standing or over-flowing rinse. In many plants, a counterflow arrangement may be used where the relatively cleaner waters at the end of the train flow backward for reuse in the preceding bowls.

The soap-alkali scouring baths are generally characterized by a temperature of 115 to 130° F and a pH of 9.5 to 10.5 while the neutral detergent baths normally have a pH of 6.5 to 7.5 and a temperature of 135 to 160° F (3).

The scouring process emulsifies the dirt and grease and produces a brown, thickly turbid waste which is often covered with a greasy scum and contains considerable, settleable mineral matter. It is strongly alkaline and very putrescible. The bowls are generally dumped once at the end of each 8-hour day at which time BOD concentration may reach 40,000 mg/1 in the first bowl and the BOD concentration in each succeeding bowl is usually about 10% of that in the previous bowl. The scouring process contributes 55 to 75% of the total BOD produced during the processing of wool fibers (1).

The grease stream produced by scouring may be passed through a centrifugal separator, permitting recovery of about 1/4 to 1/2 of the grease; the remainder of which would then be discharged with the water to waste (6). The crude, recovered grease is normally refined further to produce lanolin, a useful byproduct, with the impurities from the refinement step also going to waste.

Scoured wool liquor can be characterized by the following: BOD – 13,000 mg/1, TS – 36,000 mg/1, pH – 9 to 12 units, and water use – 2,000 to 12,000 gal/1,000 lb. product.

4.3.2 Washing After Fulling

Washing after fulling produces the second largest source of BOD during wool processing, contributing about 20 to 35% of the total (1). Fulling is a process used to shrink, tighten and smooth the wool fibers for non-woven felts or woven cloth.

There are two common methods of fulling: alkali fulling and acid fulling. In the former case, soap or synthetic detergent, soda ash, and sequestering agents are used in the fulling solution. In acid fulling, the fabric is impregnated with an aqueous solution of sulfuric acid, hydrogen peroxide, and minor amounts of metallic catalysts (chromium, copper and cobalt). In either case, the water is heated to a temperature of 90 to 100° F (5). Acid fulling is always followed by alkali fulling.

After fulling, the residual materials are washed out of the cloth, generally in a string or rope washer. The cloth is pulled between the rollers of the washer with the ends of the cloth sewn together to form a continuous string and circulated through the washer approximately 10 to 20 times. The usual procedure in this process is to subject the fulled cloth to two soapings, two warm rinses, and one cold rinse. In the first soaping, nothing is added to the water; the soaping action takes place when agitation of the fabric causes the soap or synthetic detergent to produce suds, thus washing the fabric. In the second soaping, a 2% solution of soap or synthetic detergent is used. The warm water rinsings are done at 100 to 110° F, while the cold rinse is done below 100° F. The rinse rate on most machines is usually 15,000 to 40,000 gal/hr. The total amount of water used per 1,000 pounds of wool processed averages about 40,000 gallons to 100,000 gallons (1).

Washwaters generally exhibit the following characteristics: BOD – 200 to 9,000 mg/l, TS – 4,000 mg/1, and pH – 9 to 12 units.

4.3.3 Neutralization After Carbonizing

Carbonizing of fabrics is a common finishing process which removes any traces of vegetable matter remaining on the wool. The actual process involves wetting out the fabric and soaking in a solution of 4 to 6% sulfuric acid. The fabric is then passed through a series of rollers to remove the excess acid and placed in an oven and heated from 212 to 220° F (1). The hot acid reacts chemically with vegetable matter, or any cotton fiber contaminant and oxidizes it to gases and a solid carbon residue. The wool is then passed through another set of rollers crushing the charred material and is shaken in a duster to remove the particles. A solid waste is produced during carbonizing but, with the exception of an occasional dump of contaminated acid bath, no liquid waste results. After the dusting process, the acids used in carbonizing must be removed. Acid removal is achieved by a preliminary rinse followed by neutralization in a bath of sodium carbonate (2½%) and a final rinse. Since the sulfuric acid and soda ash contribute little or no BOD, and the amount contributed by remaining vegetable matter is relatively small, the overall carbonizing process adds less than 1% of the total waste load (1).

Wastewater characteristics as a result of this processing step are as follows: BOD – 15 to 100 mg/l, TS – 4,000 mg/l, pH – 2 to 9 units, and water use – 2,000 to 16,000 gal/1,000 lb. product.

4.3.4 Bleaching

Wool is bleached if white fabric or very light shades of colored cloth are required; however, the amount of wool bleached for today's market is rather small. Bleaching of wool fibers may be accomplished after the scouring process (often the last bowl in the scouring train) or fabric may be bleached after finishing. There are three methods of bleaching wool: 1) with sulfur dioxide, 2) with hydrogen or sodium peroxide, and 3) with optical brighteners.

Wool may be bleached by reduction of color compounds with sulfur dioxide which is not a permanent bleach. A true bleach is obtained by the use of hydrogen peroxide mixed with sodium hydroxide for pH control. Another bleach employs sodium peroxide with acid for pH control.

Many plants use optical brighteners composed of various organic compounds. Although the BOD load is generally higher than for other methods, this process still contributes less than 1% of the total BOD (1).

Bleaching wastewater characteristics are as follows: BOD – 390 mg/1, TS – 900 mg/1, pH – 6.0 units, and water use – 300 to 2,700 gal/1,000 lb. product.

4.3.5 Dyeing

Wool may be dyed in fiber form (top dyeing) or after spinning (yarn dyeing) or it may be dyed as a fabric (piece dyeing). Due to the current popularity of multi-colored fabrics, yarn or stock dyeing is used more often than piece dyeing.

Currently, stock and yarn are usually dyed in pressure vessels with controlled liquid recirculation by pumping. Formerly, stock and yarn dyeing processes used open vats where paddles moved the wool through the dye bath. Although spool and skein dyeing are both in current use, most wool is dyed in skeins, placed in packages and then rewound.

The wool dyeing processes are very difficult to classify or discuss because of the very great differences in the types of dyes used and the manner in which any one type of dye is applied to the goods. In acid dyeing the temperature of the solution may vary from 140 to 212° F, and in metalized dyeing the average final temperature is 185° F (3).

Many of the chemicals used for wool dyeing are toxic, and the pH varies depending on the amount of residual alkali left in the wool fibers after the scouring process. The BOD load is contributed by the process chemicals used, and the contribution of wool dyeing to the mill's total BOD is 6 to 9% (5).

Depending upon dye method used, wastewater characteristics will be in the following range: BOD – 140 to 3,500 mg/1, TS – 2,500 to 9,100 mg/1, pH – 4.8 to 8.0 units, and water use – 2,000 to 3,000 gal/1,000 lb. product.

TABLE 4-10
BOD CONTRIBUTED BY WOOL WET PROCESSES

PROCESS	BOD SOURCES	BOD LB./1000 LB. PRODUCT (mg/l)*	WATER USE GALLONS/1000 LB. PRODUCT	REFERENCE
SCOURING:				
Soap-Alkali Method:				
Bowl 1	Natural Impurities,	(11,900 — 27,000)	N/I	5
Bowl 2	Suint, Dirt, Grease	(2,340 — 7,350)	N/I	5
Bowl 3		(150 — 400)	N/I	5
	Total Process	104.5 — 221.4	5,500 — 12,000	5
Detergent — Na$_2$SO$_4$ Method:				
Bowl 1	Natural Impurities,	(11,000 — 25,000)[1]	N/I	5
Bowl 2	Suint, Dirt, Grease	(775 — 1,560)[1]	N/I	5
Bowl 3		(115 — 260)[1]	N/I	5
	Total Process	104.5 — 221.4[2]	5,500 — 12,000	5
WASHING AFTER FULLING:				
First Soaping	Residual Material,	(3,900 — 24,000)	N/I	5
Second Soaping	Soap or Detergent	(4,000 — 4,000)	N/I	5
	Penetrants and Carding Oil			
	Total Process	31 — 94[2]	40,000 — 100,000	5
NEUTRALIZATION AFTER CARBONIZING:				
First Running Rinse	Residual Vegetable Matter	(20 — 35)	N/I	5
First Soda Ash Bath	(Very Little)	(21 — 36)	N/I	5
	Total Process	1.7 — 2.1[2]	12,500 — 15,700	5
BLEACHING:	Organic Compounds,	1.4	300 — 2,680	5
	Chemical used in process	(390)		
	(Very Little)			
DYEING:				
Acetic Acid Used	Process Chemicals	(1,440 — 3,450)	N/I	5
or				
Ammonia Sulfate Used		(140 — 1,020)	N/I	5
	Average of Process	9.0 — 34.3[2]	1,900 — 2,680	5

( )* — Indicates concentration in mg/l

[1] — These samples were taken early in the day and give a false impression of low values over the soap — alkali method. Actually, at the end of day results between processes should be similar.

[2] — No information in (mg/l), only lb/1000 lb product were given. However, the average concentration in mg/l of the process can be calculated using water use.

N/I No Information Available.

TABLE 4-11

TOTAL SOLIDS CONTRIBUTED BY WOOL WET PROCESSES

PROCESS	TOTAL SOLIDS SOURCES	TOTAL SOLIDS mg/l	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOURING:				
Soap-Alkali Method:				
Bowl 1	Dirt, Natural Impurities, Suint (Soluble Excretions and Secretions)	42,116 — 76,950	N/I	5
Bowl 2		16,650 — 32,532	N/I	5
Bowl 3		834 — 1,424	N/I	5
	Total Process	N/I	5,500 — 12,000	5
Detergent — Na_2SO_4 Method:				
Bowl 1	Dirt Sand, Natural Impurities, Suint (Soluble Excretions and Secretions)	47,108 — 91,456	N/I	
Bowl 2		5,024 — 7,856	N/I	
Bowl 3		1,052 — 2,406	N/I	
	Total Process	N/I	5,500 — 12,000	5
WASHING AFTER FULLING:				
First Soaping	Residual Matter, Chemical From Process	11,270 — 23,120	N/I	5
Second Soaping		4,516 — 5,144	N/I	5
	Total Process	N/I	40,000 — 100,000	5
NEUTRALIZATION AFTER CARBONIZING:				
First Running Rinse	Very Fine Carbon Particles, Residual Matter from Treatment	494 — 1,988	N/I	5
First Soda Ash Bath		8,678 — 10,884	N/I	5
	Total Process	N/I	12,500 — 15,700	5
BLEACHING:	Organic Compounds Used in Process	908	300 — 2,680	5
DYEING:				
Acetic Acid Used	Process Chemicals	2,418 — 5,880	N/I	5
or				
Ammonia Sulfate Used		7,344 — 9,160	N/I	5
	Average of Process	N/I	1,900 — 2,680	5

N/I No Information Available.

TABLE 4-12

CHARACTERISTICS OF WASTEWATER BY pH FROM WOOL WET PROCESSES

PROCESS	CHARACTERISTICS	pH UNIT	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOURING:				
Soap-Alkali Method	High Alkalinity Resulted From Hot Alkali Soap	9.5 — 10.5	5,500 — 12,000	5
Detergent - N_2SO_4 Method	Natural to High Alkaline	6.4 — 9.1	5,500 — 12,000	5
WASHING AFTER FULLING:	High Alkalinity Resulted From Soap and Detergent Solution	9.0 — 10.7	40,000 — 100,000	5
NEUTRALIZATION AFTER CARBONIZING:				
First Running Rinse	Acid pH Resulted From Sulfuric Acid	1.9 — 2.4	N/I	5
First Soda Ash Rinse	Alkaline pH Resulted From Soda Ash	7.9 — 9.0	N/I	5
	Total Process	N/I	12,500 — 15,700	5
BLEACHING:	Neutral	6.0	300 — 2,680	5
DYEING:				
Acetic Acid Used	Acid pH to Neutral Resulted from Acid Used	4.8 — 8.4	N/I	5
Ammonia Sulfate Used	Neutral	5.0 — 8.3	N/I	5
	Average Process	N/I	1,900 — 2,680	

N/I No Information Available.

TABLE 4-13

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY WOOL WET PROCESSES (REFERENCE 5)

PROCESS	pH	BOD		WATER USE
		LB. / 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	GALLONS / 1000 LB. PRODUCT
SCOURING: Soap-Alkali Method	9.5 — 10.5	104.5 — 221.4	63 — 71	5,500 — 12,000
WASHING AFTER FULLING:	9.0 — 10.7	31 — 94	21 — 27	40,000 — 100,000
NEUTRALIZATION AFTER CARBONIZING:	1.9 — 9.0	1.7 — 2.1	0.6 — 1	12,500 — 15,700
BLEACHING:	6.0	1.4	0.4 — 1	300 — 2,680
DYEING: Acetic Acid Used	4.8 — 8.4	9.0 — 34.3	6 — 9	1,900 — 2,680
TOTAL	6 — 11	147.6 — 353.2	100	60,200 — 133,060

TABLE 4-14

COMPARISON OF WASTEWATER CHARACTERISTICS FROM WOOL WET PROCESSES

PROCESS/	pH. UNIT				BOD, LB/1000 LB. PRODUCT (mg/l)				TOTAL SOLIDS, LB/1000 LB. PRODUCT (mg/l)				WATER USE GALLONS/1000 LB. PRODUCT			
REFERENCES	REF 1	REF 5	REF 6	REF 8	REF 1	REF 5	REF 6	REF 8	REF 1	REF 5	REF 6	REF 8	REF 1	REF 5	REF 6	REF 8
SCOURING:	N/I	9 - 10.5	N/I	10-12	2,067 (13,168)	104.5-221.4 (N/I)	300 Based on raw wool	250 (15,000)	N/I	N/I	505 Based on raw wool	600 (36,000)	2,067	5,500-12,000	10,000 Based on raw wool	2,000
WASHING AFTER FULLING:	N/I	9.0-10.7	N/I	10-12	66 (183)	31-94 (N/I)	N/I	200 (9,000)	N/I	N/I	N/I	300 (18,000)	43,333	40,000-100,000	N/I	2,000
NEUTRALIZATION AFTER CARBONIZING:	N/I	1.9-9.0	N/I	4.0	2.1 (15)	1.7-2.1 (N/I)	N/I	1.7 (100)	N/I	N/I	N/I	68 (4,000)	16,533	12,500-15,700	N/I	2,000
BLEACHING:	N/I	6.0	N/I	N/I	N/I	1.4 (390)	N/I	N/I	N/I	(908)	N/I	(N/I)	(N/I)	300-2,680	N/I	N/I
DYEING:	N/I	4.8-8.0	N/I	7.0	10.3 (398)	9.0-34.3 (N/I)	N/I	50 (3,000)	N/I	(2,418-9,160)	N/I	117 (7,000)	3,100	1,900-2,680	N/I	2,000

N/I No Information Available.

4.4 Synthetics Processing

Synthetic fibers fall into two main groups: those produced from cellulose (cellulosic) such as rayon or cellulose acetate, and those produced synthetically from organic materials (non-cellulosic) such as nylon, polyester, acrylics or modacrylics.

Synthetic fibers can be converted into fabrics in one of two ways: Continuous filament yarns can be used to manufacture 100% synthetic fabrics, or staple yarns can be used to produce fabrics that are blends of man-made fibers or man-made and natural fibers. Since each of the synthetic fibers is processed in a varying sequence of operation, each fiber will be considered separately.

4.4.1 Rayon

Rayon is 100% regenerated cellulose and for processing purposes may be considered as clean cotton. Rayon staple may be sized and desized as cotton, whereas rayon filament is generally sized with gelatin or anti-static lubricants. The sizes or lubricants are removed during the scouring process of finishing and thereby contribute a portion of the pollution load. The scouring solution itself will usually contain soluble oils, weak alkalis, and soaps or synthetic detergents which also contribute to the total waste load. The average BOD for this waste is 2,800 mg/1 of which 50 to 60% is contributed by the anti-static compounds, 30 to 40% is due to the soluble oil and 10 to 20% is due to the synthetic detergents (5).

Dyeing, the second operation which produces aqueous waste, is usually performed concurrently with rayon scouring. The main reason for scouring and dyeing in the same bath is that very little rayon is bleached due to its inherent whiteness and possible degradation of the fiber by the oxidizing agents used in bleaching. Rayon may be dyed by conventional methods using the same dyes as used for cotton, i.e. acid, vat, or dispersed. However, lower temperatures (180 to 200° F), retarding agents and lower concentrations of electrolytes are used to effect exhaustion of color.

Scouring and dyeing will generate a waste with the following characteristics: BOD – 2,800 mg/1, TS – 3,300 mg/l, TSS – 90 mg/l, pH – 8.5 units, and water use – 2,000 to 4,000 gal/1,000 lb. product.

After the scour and dye bath, rayon is subjected to a salt bath to remove residual scouring material and to assure fastness of the dyestuff. The bath contains a synthetic detergent and salt solution which is subsequently rinsed from the fabric.

Practically all the BOD of this discharge is due to residual scour and dye bath solution left in the fabric. The waste discharge has an average BOD of 58 mg/1, pH of 6.8 units, and a salt content of 4,000 to 12,000 mg/1 (5). If scouring and dyeing are the only finishing processes given rayon fabrics, the two baths will produce an equalized effluent of 1,445 mg/1 BOD and 2,000 to 6,000 mg/1 salt contained in approximately 5,000 gallons of water for each 1,000 pounds of fabric processed (9).

Special finishing, when used, will result in a BOD of 20 to 30% of total plant load. Suspended solids from finishing will contribute 60 to 85% of total plant load. Fire retardant finishes for cellulosics contain high levels of nitrogen and phosphorus.

4.4.2 Acetate

Acetate is the generic name for cellulose acetate fibers and is applied to textile fibers, yarns and threads made of such fibers. The finishing processes of acetate fibers are similar to those of rayon fibers and generally consist of the following:

- Chemical Preparation
- Scouring and Dyeing
- Rinsing
- Finishing

The usual procedure for finishing acetate fibers begins with a preliminary desizing action which removes the starch or anti-static lubricants. The anti-static compounds are solubilized by diastatic or proteolytic enzymes prior to scouring with a soap or synthetic detergent used in the actual scouring process (9). Acetate, like rayon, is usually scoured and dyed in the same bath. The type of dyes used are also similar and include dispersed dyeing, developed dyeing, acid dyeing and naphthol dyeing.

Because dispersed dyes have very low solubility in water, they are applied as a fine dispersion of the dye. Sulfonated oil, aliphatic esters, and softeners are applied with each class of dye at a concentration of 0.02 pounds per pound fiber to facilitate dyeing (4). When the fiber is swelled, the dye solution penetrates into the fiber. The rinses following dyeing remove the swelling agent; and as the fiber unswells, the dye solution is encased in the fiber.

Wastes from typical scour and dye baths exhibit a pH of 9.3 units and average 2,000 mg/1 BOD with 50 pounds of BOD produced for each 1,000 pounds of acetate fabric finished. Total suspended solids generated are approximately 600 mg/1. The combined dye/scour bath will contain anti-static desize waste (40 to 50% of the BOD load), sulfonated oil swelling agents (30 to 40% of the BOD load), aliphatic ester swelling agents (10 to 20% of the BOD load) and the softener (negligible BOD load) (9). Two rinses follow the scouring/dyeing operation, each of which contains some amount of the residual chemicals. The three processes – scour/dye/rinse produce a complete waste of 666 mg/1 BOD for each 1,000 pounds of fabric processed. The amount of water used to process 1,000 pounds of fabric averages 9,000 gallons (9). If it is desired that the acetate fabric remain white, a bleaching operation is usually performed after scouring. Typical bleaching agents are mild oxidizing agents such as hydrogen peroxide or chlorine bleaches. Two rinsing operations usually follow bleaching to remove excess materials.

If bleaching is substituted for dyeing, the BOD of the discharge of the scouring and bleaching bath is approximately 750 mg/1. The equalization of this bath with the discharges from the two rinsings will average 250 mg/l and 15 to 20 pounds of BOD in 9,000 gallons of wastewater for the processing of 1,000 pounds of cloth (9).

4.4.3 Nylon

The usual procedure involved in nylon finishing is scouring, two rinses, dyeing, and another rinse. Nylon differs from other synthetics in that approximately 1% of the fiber dissolves when scoured (3). Nylon fibers can be dyed by every class of dye; however, when nylon is used in blended fabrics, the choice of dye usually depends on the other fiber component of the blend (9).

Soap and soda ash are used in the scouring process. When wasted, the bath contains the following BOD producing compounds – the anti-static compound, soaps, and fatty esters (from the dissolving fiber components). The typical nylon scour bath averages 1,360 mg/1 and 34 pounds of BOD for each 1,000 pounds of cloth processed. The substances present in the bath contribute the following percentages to the total BOD of the bath: anti-static sizing compound (40 to 50%), soap, (40 to 50%), and fatty esters (10 to 20%) (9). Other characteristics include: pH – 10.4 units, TS – 1,900 mg/l, and water use – 7,000 gal/1,000 lb. product.

When nylon is dyed, sulfonated oils are used as dye dispersants. These dye dispersants contribute practically all of the process BOD, which amounts to an average of 600 mg/1 and 15 pounds for each 1,000 pounds of cloth dyed (3). Dye wastewaters exhibit a pH of approximately 8.4 units.

The two rinses between the scouring and dyeing processes and the rinse following dyeing are low in BOD, which is caused by scouring and dyeing process chemicals that remained on the fabric. If the wastes from these five processes are equalized, scouring and dyeing 1,000 pounds of nylon fabric results in a waste stream which will average 340 mg/1 and 43.2 pounds of BOD in 15,000 gallons of wastewater. The BOD contribution of the scouring process is roughly 65%, the remaining BOD being contributed by the dyeing process (5).

4.4.4 Acrylic/Modacrylic

Acrylic/modacrylic fibers are defined as those in which the fiber forming substances are any long chain synthetic polymer composed of at least 85% by weight of acrylonitrile units for acrylic and less than 85% but at least 35% for modacrylic. The basic finishing processes for acrylic include:

- Scouring
- Dyeing or Bleaching

- Scouring
- Special Finishing

Acrylic fabric normally is scoured with a weak alkali solution, an anti-static lubricant and soap or detergent. This operation may be done by a variety of equipment including the following:

- Beam Dyeing Equipment
- Rope Soaper
- Jig Scour
- Beck Scour
- Drum of Paddle Scour

After scouring, the material is rinsed to remove excess chemicals in preparation for the dye bath. Acrylic scour and rinse waste have an average BOD of 2,190 mg/1 of which 30 to 40% is due to anti-static lubricants and 50 to 70% is due to soap (1). The pH ranges from 8.8 to 9.7 units.

Dyeing is the most important part of the acrylic finishing process. Acrylic fibers are hydrophobic, resisting water adsorption almost completely and therefore present special problems.

There are several alternate methods of dyeing acrylics. The most prevalent method is basic dyeing.

High temperature and pressure are sometimes used with dispersed and acid dyes on acrylic material. A temperature of 212° F may eliminate the need for carriers by softening and swelling the fibers so dyes can penetrate. This method produces high temperature wastes with no BOD.

Thermosol padding is an alternate means of dyeing which produces only occasional batches of soap and rinse water. This method involves oven dyeing at 347 to 392° F and is a potential source of air pollution (1).

Dye wastes are characterized by the following ranges: BOD – 175 to 2,000 mg/l, TS – 800 to 1,900 mg/l, pH – 1.5 to 3.7 units, and water use – 2,000 to 4,000 gal/1,000 lb. product.

Acrylics normally receive a final scour and rinse with synthetic detergent and pine oil. The scour waste has an average BOD of 700 mg/1, 90% of which is contributed by the pine oil (1). Other characteristics include TS – 800 to 1,900 mg/1, pH – 7.1 units, and water use – 8,000 to 10,000 gal/1,000 lb. product.

4.4.5 Polyester

The American market consumes more polyester than any of the other man-made fibers (10). Because of the large consumption and character of the fiber, special dyeing and finishing process have been developed. Polyester fabric finishing is usually carried out in the following order: scour, rinse, dye, and scour again. Because chemical impurities are virtually absent in polyester fibers, only relatively light scouring is needed to prepare them for dyeing. Scouring solutions consist of weak alkalis, lubricants and soap. After scouring, the material is rinsed to remove excess chemicals and to prepare it for dyeing. The polyester scour waste average 500 to 800 mg/l of BOD. The processing of 1,000 pounds of polyester fabric will produce 15.5 pounds of BOD, of which 90% is contributed by the anti-static compounds used for lubrication and sizing (5).

Polyester may be dyed in several different ways. Conventional dyeing temperatures (room temperature to boiling) may be used, but carriers are needed to take the dye into the fiber. A second method eliminates the carriers, but high temperatures (250° F) and pressures (50 psi) are required to get desirable results. Carriers used in polyester dyeing include: methyl naphthalene, butyl benzoate, diphenyl oxide, percloroethylene, orthophenylphenol, biphenyl, benzylalcohol and chloro-benzenes. To use these carriers at conventional temperatures, high concentrations of from 0.06 to 0.4 pounds of carrier to 1 pound of fiber are required (3).

Thermosol padding is another means of dyeing which produces only occasional batches of soap and rinse water. This method involves coating the fabric with the dyestuff and oven drying at 347 to 392° F (1).

Because of the high concentrations at which they are used and the inherent high rate of BOD, the emulsifying and dissolving agents used in polyester dyeing will produce high BOD loads.

At the present time butyl benzoate and percloroethylene are the most widely used dye carriers. The two rinses of polyester finishing are usually low in BOD as the result of chemicals held in the cloth after scouring and dyeing. The processing of polyester uses an average of 15,000 gallons of water per 1,000 lb. of fiber processed (5). Dye take-up and shrinkage of synthetic fibers can be effected by heat-setting up to 450° F (1). Once this is done, the dimensional stability of the cloth cannot be changed without repeating the process at a higher temperature. Heat-setting is widely practiced and may occur at any of several places in the series of finishing processes. The most usual point of application is before dyeing. This may be a dry process using hot air, radiant heat, or a hot roll. Steam under pressure and hot water are also used. The two most prevalent methods in 1963 were hot air and steam (1). Wastes from this process are in the form of hot air, hot water, or steam. The last part of the overall finishing process may include such processes as:

- Water proofing
- Water-repellent treatment
- Oil-repellent treatment
- Resin finishing
- Latex backing
- Water retardant treatment

- Modification of fabric hand
- Drying

Any other minor specialized treatment falls into this category. These processes may contribute wastes, but the effect is generally not significant.

TABLE 4-15
BOD LOADS CONTRIBUTED BY RAYON FIBER PROCESSES

PROCESS	BOD SOURCES	BOD LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOUR & DYE:	Anti-statics compounds, soluble oil, synthetic detergent	50 - 70 (2,832)	2,000 - 4,000	5, 9
SALT BATH:	Synthetic Detergent	0 - 3 (58)	500 - 1,500	5, 9
SPECIAL FINISHING:	Process Chemicals	20 (1,600)	500 - 1,500	5, 9

TABLE 4-16
TOTAL SOLIDS AND TOTAL SUSPENDED SOLIDS CONTRIBUTED BY RAYON FIBER PROCESSES

PROCESS	TOTAL SOLIDS & TOTAL SUSPENDED SOLIDS SOURCES	TOTAL SOLIDS LB. / 1000 LB. PRODUCT (mg/l)	T.S.S. LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOUR & DYE:	Anti-static compounds residual	25 - 39 (3,334)	0 - 3 (90)	2,000 - 4,000	5, 9
SALT BATH:	Residual matter from scour & dye, chloride sulfate	20 - 200 (4,890)	2 - 6 (160 - 480)	500 - 1,500	5, 9
SPECIAL FINISHING:	Process Chemicals	3 - 100	3 - 50	500 - 1,500	5, 9

TABLE 4-17

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY RAYON FIBER PROCESSES (REFERENCES 5, 9)

		BOD		TOTAL SOLIDS		TOTAL SUSPENDED SOLIDS		WATER USE
		LB	%	LB	%	LB	%	GALLONS
PROCESS	pH	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT
SCOUR & DYE:	8.5	50 - 70 (2,832)	71 - 75	25 - 39 (3,334)	52 - 12	0 - 3 (90)	0 - 5	2,000 - 4,000
SALT BATH:	6.8	0 - 3 (58)	0 - 3	20 - 200 (4,890)	42 - 59	2 - 6 (160 - 480)	40 - 10	500 - 1,500
SPECIAL FINISHING:	N/I	20 (1,600)	29 - 22	3 - 100 (N/I)	6 - 29	3 - 50 (N/I)	60 - 85	500 - 1,500
GRAND TOTAL		70 - 93	100	48 - 339	100	5 - 59	100	3,000 - 7,000

N/I No Information Available.

TABLE 4-18
BOD LOADS CONTRIBUTED BY ACETATE FIBERS

PROCESS	BOD SOURCES	BOD LB. 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS 1000 LB. PRODUCT	REFERENCES
SCOUR & DYE *1: or	Anti-static lubricants, oil, dye	40 - 60 (2,000)	4,000 - 6,000	5, 9
SCOUR & BLEACHED:	Synthetic detergent, hydrogen peroxide	25 - 38 (750)	4,000 - 6,000	5, 9
FIRST RINSE:	negligible	--	--	5, 9
SECOND RINSE:	negligible	--	--	5, 9
SPECIAL FINISHING:	Process Chemicals	40 (1,000 - 1,600)	3,000 - 5,000	5, 9
*1 SCOUR & DYE:	Surfactant & Disperse Dye	6 (72)	1,000	6

TABLE 4-19
TOTAL SOLIDS AND TOTAL SUSPENDED SOLIDS CONTRIBUTED BY ACETATE FIBER PROCESSES

PROCESS	TOTAL SOLIDS & TOTAL SUSPENDED SOLIDS SOURCES	TOTAL SOLIDS LB. 1000 LB. PRODUCT (mg/l)	T.S.S. LB. 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS 1000 LB. PRODUCT	REFERENCES
SCOUR & DYE *2: or	Anti-static compounds residual	60 (1,778)	1 - 20 (600)	4,000 - 6,000	5, 9
SCOUR & BLEACHED:	Synthetic detergent residual from scour	26 - 47 (799 - 946)	N/I	4,000 - 6,000	5, 9
FIRST RINSE:	negligible	--	--	--	5, 9
SECOND RINSE:	negligible	--	--	--	5, 9
SPECIAL FINISHING:	Process Chemicals	3 - 300 (120 - 2,400)	3 - 50 (120 - 1,200)	3,000 - 5,000	5, 9
*2 SCOUR & DYE:	Residual from scour	TDS 10 (120)	indeterminate	10,000	6

N/I No Information Available.

TABLE 4-20

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY ACETATE FIBER PROCESSES (REFERENCES 5, 9)

		BOD		TOTAL SOLIDS		TOTAL SUSPENDED SOLIDS		WATER USE GALLONS
		LB	%	LB	%	LB	%	
PROCESS	pH	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT (mg/l)	CONTRIBUTION OF TOTAL	1000 LB. PRODUCT
SCOUR & DYE:	9.3	40 - 60 (2,000)	50	60 (1,778)	95 - 38	1 - 20 (600)	25 - 29	4,000 - 6,000
SPECIAL FINISHING:	N/I	40 (1,000 - 1,600)	50	3 - 100 (120 - 2,400)	5 - 62	3 - 50 (120 - 1,200)	75 - 71	3,000 - 5,000
GRAND TOTAL		80 -120	100	63 - 160	100	4 - 70	100	7,000 - 11,000

N/I No Information Available.

TABLE 4-21
BOD LOADS CONTRIBUTED BY NYLON FIBER PROCESSES

PROCESS	BOD SOURCES	BOD LB.	WATER USE GALLONS	REFERENCES
		1000 LB. PRODUCT (mg/l)	1000 LB. PRODUCT	
SCOUR *1:	Anti-static lubricants, fatty esters	30 - 40 (1,360)	6,000 - 8,000	5, 9
DYE *1:	Residual from scour, dye, sulfonates	5 - 20 (368)	2,000 - 4,000	5, 9
SPECIAL FINISHING:	Process Chemicals	10 (N/I)	4,000 - 6,000	5, 9
*1 SCOUR & DYE:				
Disperse Dye	Anionic surfactant, softener, disperse dye	24 (221)	10,000 - 16,000	6
Acid Dye	Acetic acid, ammonium, acetate acid, softener	4.5 - 15.5 (42 - 143)	10,000 - 16,000	6
Cationic Dye	Acetic acid, softener, nonionic surfactant	5 (46)	10,000 - 16,000	6

N/I No Information Available.

TABLE 4-22
TOTAL SOLIDS AND TOTAL SUSPENDED SOLIDS CONTRIBUTED BY NYLON FIBER PROCESSES

PROCESS	TOTAL SOLIDS & TOTAL SUSPENDED SOLIDS SOURCES	TOTAL SOLIDS LB.	T.S.S. LB.	WATER USE GALLONS	REFERENCES
		1000 LB. PRODUCT (mg/l)	1000 LB. PRODUCT (mg/l)	1000 LB. PRODUCT	
SCOUR *2:	Anti-static compounds residual	30 - 50 (1,882)	20 - 40 (N/I)	6,000 - 8,000	5, 9
DYE *2:	Residual from scour	20 - 34 (641)	2 - 42 (N/I)	2,000 - 4,000	5, 9
SPECIAL FINISHING:	Process Chemicals	3 - 100 (N/I)	3 - 50 (N/I)	4,000 - 6,000	5, 9
*2 SCOUR & DYE:					
Disperse Dye	Residual from scour	T.D.S. 55 - 60 (507 - 553)	indeterminate	10,000 - 16,000	6
Acid Dye	Residual from scour	T.D.S. 125 - 135 (1,150 - 1,250)	indeterminate	10,000 - 16,000	6
Cationic Dye	Residual from scour	T.D.S. 105 -115 (970 - 1,060)	indeterminate	10,000 - 16,000	

N/I No Information Available.

TABLE 4-23

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY NYLON FIBER PROCESSES (REFERENCES 5, 9)

PROCESS	pH	BOD		TOTAL SOLIDS		TOTAL SUSPENDED SOLIDS		WATER USE
		LB. 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB. 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB. 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	GALLONS 1000 LB. PRODUCT
SCOUR:	10.4	30 - 40 (1,360)	67 - 57	30 - 50 (1,882)	57 - 28	20 - 40 N/I	80 - 30	6,000 - 8,000
DYE:	8.4	5 - 20 (368)	11 - 29	20 -34 (641)	38 - 18	2 - 42 N/I	8 - 32	2,000 - 4,000
SPECIAL FINISHING:	N/I	10 (N/I)	22 - 14	3 - 100 (N/I)	5 - 54	3 - 50 (N/I)	12 - 38	4,000 - 6,000
GRAND TOTAL	N/I	45 - 70	100	53 - 184	100	25 - 132	100	12,000 - 18,000

N/I No Information Available.

TABLE 4-24

BOD LOADS CONTRIBUTED BY ACRYLIC/MODACRYLIC FIBERS PROCESSES

PROCESS	BOD SOURCES	BOD LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCES
SCOUR:				
	Synthetic detergent, Pine oil	45 - 90 (2,190)	6,000 - 8,000	5, 9
DYE:	Dye, residual from scour	2 - 40 (175 - 2,000)	1,000 - 4,000	5, 9
FINAL SCOUR:	Anti-static Lubricants, synthetic detergent	10 - 25 (668)	8,000 - 10,000	5, 9
SPECIAL FINISHING:	Process Chemicals	60 (N/I)	5,000 - 7,000	5, 9

N/I No Information Available.

TABLE 4-25

TOTAL SOLIDS AND TOTAL SUSPENDED SOLIDS CONTRIBUTED BY ACRYLIC/MODACRYLIC FIBERS PROCESSES

PROCESS	TOTAL SOLIDS & TOTAL SUSPENDED SOLIDS SOURCES	TOTAL SOLIDS LB. / 1000 LB. PRODUCT (mg/l)	T.S.S. LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCES
SCOUR:	Residual matter	12 - 20 (1,874)	25 - 50 (N/I)	6,000 - 8,000	5, 9
DYE:	Dye, residual from scour	6 - 9 (833 - 1,968)	5 - 20 (N/I)	2,000 - 4,000	5, 9
FINAL SCOUR:	Detergent, anti-static compound	4 - 12 (833 - 1,968)	3 - 7 (N/I)	8,000 - 10,000	5, 9
SPECIAL FINISHING:	Process Chemicals	3 - 100 (N/I)	3 - 50 (N/I)	5,000 - 7,000	5, 9

N/I No Information Available.

TABLE 4-26

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY ACRYLIC/MODACRYLIC FIBERS PROCESSED (REFERENCES 5, 9)

PROCESS	pH	BOD		TOTAL SOLIDS		TOTAL SUSPENDED SOLIDS		WATER USE
		LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	GALLONS 1000 LB. PRODUCT
SCOUR:	9.7	45 - 90 (2,190)	38 - 42	12 - 20 (1,874)	48 - 14	25 - 50 (N/I)	69 - 39	6,000 - 8,000
DYE:	1.5-3.7	2 - 40 (175 - 2,000)	2 - 18	6 - 9 (833 - 1,968)	24 - 6	5 - 20 (N/I)	14 - 16	2,000 - 4,000
FINAL SCOUR:	7.1	10 - 25 (668)	9 - 12	4 - 12 (833 - 1,968)	16 - 9	3 - 7 (N/I)	8 - 6	8,000 - 10,000
SPECIAL FINISHING:	N/I	60 (N/I)	51 - 28	3 - 100 (N/I)	12 - 71	3 - 50 (N/I)	9 - 39	5,000 - 7,000
GRAND TOTAL		117 - 215	100	25 - 141	100	36 - 127	100	21,000 - 29,000

N/I No Information Available.

TABLE 4-27
BOD LOADS CONTRIBUTED BY POLYESTER FIBERS PROCESSES

PROCESS	BOD SOURCES	BOD LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOUR *1:	Anti-static compounds	15 - 25 (500 - 800)	3,000 - 5,000	5, 9
DYE *1:	Dye, emulsifying and disolving agents	15 - 800 (480 - 27,000)	2,000 - 4,000	5 9
FINAL SCOUR:	Synthetic detergents	15 - 25 (650)	2,000 - 4,000	5, 9
SPECIAL FINISHING:	Process chemicals	2 - 80 (N/I)	1,000 - 3,000	5, 9
*1 SCOUR & DYE:				
Atmospheric Beck	Biphenyl phenol, Anionic surfactant, Acetic Acid, Sodium Hydrosulfite	100 - 225 (343 - 770)	35,000	6
Pressure Beck	Butyl benzoate, Anionic Surfactant, Acetic acid, Sodium Hydrosulfite	33 - 70 (113 - 240)	35,000	6

N/I No Information Available.

TABLE 4-28
TOTAL SOLIDS AND TOTAL SUSPENDED SOLID CONTRIBUTED BY POLYESTER FIBER PROCESSES

PROCESS	TOTAL SOLIDS & TOTAL SUSPENDED SOLIDS SOURCES	TOTAL SOLIDS LB. / 1000 L B. PRODUCT (mg/l)	T.S.S. LB. / 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS / 1000 LB. PRODUCT	REFERENCE
SCOUR *2:	Residual matter	25 - 35 (N/I)	5 - 15 (N/I)	3,000 - 5,000	5, 9
DYE *2:	Dye, residual from scour	30 - 200 (N/I)	—	2,000 - 4,000	5, 9
FINAL SCOUR:	Synthetic detergents	10 - 50 (N/I)	3 - 50 (N/I)	2,000 - 4,000	5, 9
SPECIAL FINISHING:	Process Chemicals	3 - 100 (N/I)	3 - 50 (N/I)	1,000 - 3,000	5, 9
*2 SCOUR & DYE:					
Atmospheric Beck	Residual from scour	TDS 80 - 90 (275 - 310)	indeterminate	35,000	6
Pressure Beck	Residual from scour	TDS 80 - 90 (275 - 310)	indeterminate	35,000	6

N/I No Information Available.

TABLE 4-29

AN EXAMPLE OF POLLUTIONAL LOADS CONTRIBUTED BY POLYESTER FIBER PROCESSES

PROCESS	pH	BOD		TOTAL SOLIDS		TOTAL SUSPENDED SOLIDS		WATER USE
		LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	LB 1000 LB. PRODUCT (mg/l)	% CONTRIBUTION OF TOTAL	GALLONS 1000 LB. PRODUCT
SCOUR:	N/I	15 - 25 (500 - 800)	32 - 3	25 - 35 (N/I)	37 - 9	5 - 15 N/I	45 - 13	3,000 - 5,000
DYE:	N/I	15 - 800 (480 - 27,000)	32 - 86	30 - 200 (N/I)	44 - 52	—	0	2,000 - 4,000
FINAL SCOUR:	N/I	15 - 25 (650)	32 - 3	10 - 50 (N/I)	15 - 13	3 - 50 (N/I)	27 - 43	2,000 - 4,000
SPECIAL FINISHING:	N/I	2 - 80 (N/I)	4 - 8	3 - 100 (N/I)	4 - 26	3 - 50 (N/I)	28 - 44	1,000 - 3,000
GRAND TOTAL	N/I	47 - 930	100	68 - 385	100	11 - 115	100	8,000 - 16,000

N/I No Information Available.

4.5 Synthetic Blends

Materials of cotton and synthetic fibers or wool and synthetic fibers are usually processed as would normally be performed on the 100% natural fiber. Tables 4-30 and 4-31 present typical data for various finishing operations of cotton/synthetic blended fabric.

TABLE 4-30

POLLUTIONAL LOADS CONTRIBUTED BY 50/50 COTTON/POLYESTER BLEND FABRIC MANUFACTURING PROCESSES (REFERENCE 6)

PROCESS	pH	BOD LB. 1000 LB. PRODUCT	(mg/l)	TOTAL SUSPENDED SOLIDS LB. 1000 LB. PRODUCT	(mg/l)	TOTAL DISSOLVED SOLIDS LB. 1000 LB. PRODUCT	(mg/l)	OIL & GREASE LB. 1000 LB. PRODUCT	(mg/l)	COLOR LB. 1000 LB. PRODUCT	(mg/l)	TOXIC MATERIAL LB. 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS 1000 LB. PRODUCT
DESIZING:													
Enzyme Starch	6 - 8	38.5	(3,078)	77	(6,155)	19.8	(1,583)	3.6	(288)	--		--	1,500
Polyvinyl Alcohol (PVA)	6 - 8	2.5	(200)	5.0	(400)	50.4	(4,029)	2.4	(192)	--		--	1,500
Carboxymethyl Cellulose (CMC)	6 - 8	3.93	(314)	5.0	(400)	54.4	(4,349)	9.4	(751)	--		--	1,500
SCOURING:													
Unmercerized, Greige Fabric	12.0	10.8	(432)	5.0	(200)	9.8	(392)	20	(799)	--		P = 0.64 (26)	3,000
Mercerized, Greige Fabric	12.0	8.34	(333)	5.0	(200)	9.7	(387)	15	(100)	--		P = 0.64 (26)	3,000
MERCERIZING:													
Greige Fabric	12.0	5.72	(343)	5.0	(300)	77	(4,616)	5	(300)	--		--	2,000
Scoured Fabric	12.0	3.2	(192)	5.0	(300)	77	(4,616)	--		--		--	2,000
Bleached Fabric	12.0	1.3	(76)	5.0	(300)	72	(4,317)	--		--		--	2,000
BLEACHING:													
Hydrogen Peroxide (Woven Goods)	10.0	1.3	(78)	4.0	(240)	20	(1,199)	--		--		P = 0.68 (41)	2,000
Hydrogen Peroxide (Knit Goods)	12.0	15.3	(183)	--		--		--				P = 0.6 (7)	10,000
Hydrogen Peroxide (Yarn Goods)	10.0	13.8	(138)	--		50	(500)	1.0	(10)	--		P = 0.6 (6)	12,000
DYEING: *1													
Direct & Disperse Dyeing (Woven Goods)	6 - 8	10.7	(257)	--		114	(2,734)	--		0.5	(12)	P = 0.76 (18)	5,000
Vat & Disperse Dyeing (Woven Goods)	12.0	22.8	(547)	--		122	(2,926)	--		1.38	(33)	P = 0.76 (18)	5,000
Sulfur & Disperse Dyeing (Woven Goods)	11.0	22.8	(547)	--		69.7	(1,671)	--		2.1	(50)	P = 0.76 (18)	5,000
Napthol & Disperse Dyeing (Woven Goods)	11.0	13.8	(331)	--		57.2	(1,372)	--		0.55	(13)	P = 0.76 (18)	5,000
Fiber Reactive & Disperse Dyeing (Woven Goods)	12.0	13.5	(324)	--		192	(4,604)	--		0.68	(16)	P = 0.76 (18)	5,000
PRINTING:													
Pigment (Woven Goods)	6 - 8	1.26	(101)	0.13	(10)	2.5	(200)	--		0.05	(4)	--	1,500
Pigment (Knit Goods)	6 - 8	1.26	(101)	0.13	(10)	2.5	(200)	--		0.05	(4)	--	1,500
Vat Dye (Woven Goods)	10.0	21.5	(644)	25	(750)	34	(1,019)	--		0.5	(15)	--	4,000
Vat Dye (Knit Goods)	10.0	21.5	(644)	25	(750)	35	(1,049)	--		0.5	(15)	--	4,000
FINISHING:													
Resin Finishing (Woven Goods)	6 - 8		(96)	--		22	(1,759)	-- --		--			
Resin Finishing	6 - 8	6.32	(505)	12	(959)	17.3	(1,383)	--		--		Zn = 0.7 (56)	1,500
Flat curing (Woven Goods)												Zn = 1.3 (104)	1,500

P = Phosphorous

Zn = Zinc

TABLE 4-31

POLLUTIONAL LOADS CONTRIBUTED BY 50/50 COTTON/POLYESTER BLEND FABRIC MANUFACTURING PROCESSES (REFERENCE 6) DYEING INCLUDING SCOURING OR PARTIAL BLEACHING

PROCESS	pH	BOD LB. 1000 LB. PRODUCT (mg/l)	TOTAL SUSPENDED SOLIDS LB. 1000 LB. PRODUCT (mg/l)	TOTAL DISSOLVED SOLIDS LB. 1000 LB. PRODUCT (mg/l)	OIL & GREASE LB. 1000 LB. PRODUCT (mg/l)	COLOR LB. 1000 LB. PRODUCT (mg/l)	TOXIC MATERIAL LB. 1000 LB. PRODUCT (mg/l)	WATER USE GALLONS 1000 LB. PRODUCT
Direct & Disperse (Knit Goods)	6 - 8	56 (224)	--	205 (819)	--	0.5 (2)	P = 4.3 (17)	30,000
Direct & Disperse (Yarn Goods)	6 - 8	39.5 (189)	--	165 (791)	1.0 (5)	0.5 (2)	P = 3.0 (14)	25,000
Developed & Disperse (Knit Goods)	1 - 2	60 (240)	--	245 (979)	--	0.85 (3)	P = 4.3 (17)	30,000
Developed & Disperse (Yarn Goods)	1 - 2	40.8 (196)	--	220 (1,055)	1.0 (5)	0.85 (4)	P = 3.0 (14)	25,000
Vat & Disperse (Knit Goods)	12.0	68.4 (273)	--	189 (755)	--	1.4 (6)	P = 4.3 (17)	30,000
Vate & Disperse (Yarn Goods)	12.0	51.3 (246)	--	173 (830)	1.0 (5)	1.4 (7)	P = 3.0 (14)	25,000
Sulfur & Disperse (Knit Goods)	6 - 8	72.9 (291)	--	170 (679)	--	2.25 (9)	P = 4.3 (17)	30,000
Sulfur & Disperse (Yarn Goods)	6 - 8	53.1 (255)	--	160 (767)	1.0 (5)	2.25 (11)	P = 3 (14) Cr = 1.5 (7)	25,000
Napthol & Disperse (Knit Goods)	10.0	65.6 (262)	--	150 (600)	--	0.85 (3)	P = 4.3 (17)	30,000
Napthol & Disperse (Yarn Goods)	6 - 8	47.0 (225)	--	142 (681)	1.0 (5)	0.55 (3)	P = 3.0 (14)	25,000
Fiber Reactive & Disperse (Knit Goods)	12.0	62.7 (251)	--	143 (572)	--	0.675 (3)	P = 4.3 (17)	30,000
Fiber Reactive & Disperse (Yarn Goods)	12.0	45.8 (220)	--	218 (1,046)	1.0 (5)	0.7 (3)	P = 3.0 (14)	25,000

P = Phosphorus
Cr = Chromium

4.6 Individual Mill Operations

4.6.1 Introduction

The data presented in the preceding part of Chapter 4 dealt with individual operations within each of the basic types of textile mills (i.e. cotton, wool, synthetic). In order to present a more realistic view and characterize the types of textile mills now in operation, the results of two recent nationwide plant investigations will be discussed in this section. The first of these reports was prepared by the Institute of Textile Technology (ITT) and Hydroscience, Inc. for the American Textile Manufacturers Institute, Inc. (ATMI) and the Carpet and Rug Institute (CRI) (11). The second study performed by Lockwood Greene Engineers, Inc. for the National Commission on Water Quality (NCWQ) was completed in 1975 (12). The data collected for the latter represents approximately 400 returns from a mailed survey.

4.6.2 ATMI Study

Appendix E is the actual data collected by ATMI and CRI during the development of the "Blue Book." The data was collected in 1972 and represents actual field investigations and data submissions by a number of textile industries. The values presented are from 309 investigations considered valid and are probably the most qualitative concerning raw textile waste which are currently available. The data is presented for 12 of 13 categories defined by ATMI and CRI Category 7 "Carpet Backing and Foam" has been omitted because of no data input.

The following description of industry categories (presented briefly in Chapter 3) has been taken verbatim from the ATMI-CRI "Blue Book" and is included to characterize the data sources.

> The principal basis for determining into which of the 13 categories a particular plant should be placed is the configuration of the predominant material being processed; i.e., knit fabric, woven fabric, carpet, yarn, etc. Special processes, such as wool scouring and latex application, provide additional definition. Review of the current structure of the textile industry also indicates material configuration to be the principal factor for classification of individual plants. Obviously, clear definition of the categories is essential in the administration of a viable program, and the following definitions for each category are suggested:

4.6.2.1 Category 1 – Wool Scouring

Plant operations for the cleaning of raw wool fiber stock. Generally the major wet operation associated with wool top manufacture and combing. May be a separate commission operation or integral to a large mill such as a carpet manufacturing plant.

4.6.2.2 Category 2 – Wool Finishing

Plants processing principally fabrics of wool which may require extremes of pH in finishing, such as fulling, carbonizing and scouring.

4.6.2.3 Category 3 – Greige Mill

The manufacture of yarn or unfinished fabric which is shipped for subsequent manufacture or finishing. Essentially a "dry" operation except for the application of lubricants or sizes to the yarn to facilitate fabric manufacture.

4.6.2.4 Category 4 – Woven Fabric Finishing

The finishing of all woven fabric except wool fabrics. Includes printing, dyeing and other wet finishing operations.

4.6.2.5 Category 5 – Knit Fabric Finishing

The finishing of all knit fabrics except wool fabrics. Predominant fibers processed tend to be synthetic.

4.6.2.6 Category 6 – Greige Mill plus Woven Fabric Finishing

Manufacture of unfinished and finished woven fabrics in the same location. A combination of Groupings 3 and 4.

4.6.2.7 Category 7 – Carpet Backing and Foam Application

Plants which fabricate finished carpets by assembly of previously-processed carpet or rug fabric, such as tufted, woven or needle punched fabric and secondary backing fabric. May also include application of foam, vinyl and other component materials.

4.6.2.8 Category 8 – Integrated Carpet Mill

Plants involved in the wet finishing and in most cases also the fabrication of finished carpets and rugs. Typically includes carpet dyeing and printing operations as well as fabrication processes described in Group 7.

4.6.2.9 Category 9 – Stock and Yarn Dyeing and Finishing

Plants which dye or finish textiles in the fiber or yarn form. Includes generally batch processing operations such as stock dyeing, skein dyeing, thread dyeing and finishing, textile and carpet yarn package dyeing, space dyeing and beam dyeing.

4.6.2.10 Category 10 – Greige Mill plus Finishing Yarn and Fabrics

An extension of Group 6 to include also the finishing of yarn and/or knit fabrics.

4.6.2.11 Category 11 – Combined Materials Finishing, Stock, Yarn, Wovens, Knits

Plant dyeing and finishing different material forms. Typically involves various combinations of Groups 4, 5 and 9.

4.6.2.12 Category 12 – Multiple-Operation, Commission House

Large plants carrying out an extremely varied and variable finishing operation.

4.6.2.13 Category 13 – Specialized Finishing

Plants carrying out processes not within the scope of this study; i.e., coating, tire cord and fabric manufacture, nonwovens, etc.

Categories 3, 4, 5, 6, 8 and 9 are essentially those as originally proposed in the July 24, 1972, Effluent Limitation Guidance publication. Categories 1 and 2 have been modified to separate out wool scouring, and Category 7 has been used to separate out backing operations. Category 10 and 11 are characteristic combinations of other groups, and Category 12 covers the commission finishing operation. Category 13 covers specialized operations for which little information is available, and plants in this category are likely outside the scope of the general interest of the guidelines program.

"Finishing" as used in the preceding categories should be understood to include broadly all wet-processing operations, such as dyeing, printing, mercerizing, scouring and other operations used in the finishing of textile materials. As proposed from a preliminary analysis of data and information, each of the categories accounts for a major identifiable segment of the textile and carpet industry, having characteristic water use and/or particular effluent characteristics or problems. With the above definition, 95% of the plants participating in this project could be identified with a single category, and the remaining plants were identifiable with combinations of two or possibly three categories.

In most cases the combining of categories may be carried out with a weighted average, prorated on production, of values for each of the characteristic operations being carried out. In other cases, however, additive combinations may be necessary, as in the case of a plant which incorporated wool scouring with other processes. Where combinations are necessary, each case should be carefully appraised on an invididual basis.

While further refinement of these categories may reveal better definition of effluent generating operations of individual plants (for example, fiber type and blend may provide a rationale for subdividing the major categories), it is believed that the above principal category can provide a workable basis for identifying characteristic effluent volumes and types.

4.6.3 National Commission on Water Quality Study

This Lockwood Greene study formulated eleven categories. These categories are listed and defined below and correlate with the wastewater characteristics tabulation provided as Appendix F.

4.6.3.1 Category 1 – Wool and Animal Hair Scouring

This category includes all scouring operations for wool and other animal hair fibers. It includes any plant which receives grease wool or other animal hair fibers and scours to remove the natural oils and impurities. Generally this is the major wet operation associated with top manufacturing and combing and may be a separate commission operation or integral to a large mill such as a carpet manufacturing plant. For the purpose of this report, wool is defined as fibers taken from the fleece of a sheep. Other animal hair fibers include the hair from the angora or cashmere goat as well as specialty fibers such as camel, alpaca, llama and vicuna.

4.6.3.2 Category 2 – Wool Raw Stock, Top and Yarn Dyeing

This category covers the dyeing of raw stock, top, or yarn in wool or other animal hair fibers and is normally separated from either wool scouring or fabric dyeing operations. It should be separated from wool scouring (category No. 1) due to the character of the waste since wool scouring is more normally associated with grease wool and the manufacture of natural wool top. It is separated from category 11 (Raw Stock and Yarn Dyeing of Cotton and Synthetic Fibers and Yarns) due to the character of the waste. It is also separated on the basis of processing equipment required and organization in the industry. There is some overlapping of this category with others, however, this is normally a separate operation.

4.6.3.3 Category 3 – Wool and Other Animal Hair Fabric Finishing

This category includes the dyeing and finishing of fabrics which are made of wool, other animal hair fibers or blends of wool and synthetics. Both woven and knit fabrics are included, and processes used could include printing, dyeing and wet or dry finishing. This category has been differentiated from other finishing categories because of the wide variety of chemicals used to process the wool fabric such as are used in carbonizing.

4.6.3.4 Category 4 – Woven Dry Processing Mill

This category covers most greige mill operations which are relatively dry in comparison to a true wet operation. Generally, the only wet operation is in the slashing of warp yarn. Slashing is the application of lubricants and sizing (starch, PVA, CMC) where the only waste generated is in the occasional dumping of starch batches and wash down of the size mixing and slasher area.

4.6.3.5 Category 5 – Adhesive Related Dry Processing Mill

This category covers processes which are basically dry but have some waste and wash down of the bonding or adhesive chemicals which are normally latex compounds. Operations included are laminating, coating, nonwoven carpet backing, and flocking. This is separated from category 4 due to different waste characteristics and volumes.

4.6.3.6 Category 6 – Woven Fabric Finishing of Cotton and Cotton/Synthetic Blends

This category is one of the most important since these plants produce most of the wastewater effluent load in the textile industry. Processes included are desizing, scouring, bleaching, mercerizing, dyeing, printing, resin treatment, and other special finish applications. Included in this category are 100% cotton and cotton/synthetic blends.

4.6.3.7 Category 7 – Woven Fabric Finishing – Others

This category covers all fibers other than those in category No. 6 and includes 100% synthetics, bast fibers, glass, silk and metallic fibers. This category comprises a small percentage of the waste load and is separated for this reason as well as because of the processing methods required, i.e. no mercerizing, less bleaching and less use of resins.

4.6.3.8 Category 8 – Knit Fabric Finishing of Cotton and Cotton/Synthetic Blends

This is the largest category of the knit fabric finishing categories and covers 100% cotton and cotton/synthetic blends. Production processes can include bleaching, dyeing, printing, resin treatment or other special finishing. This is set aside from hosiery and 100% synthetic knit goods due to the production processes required and to the character of the effluent.

4.6.3.9 Category 9 – Knit Fabric Finishing of 100% Synthetics

This category covers all 100% synthetic fabrics including polyesters, cellulosics, nylon and acrylics and covers both hosiery operations and outerwear fabrics. These fabrics are separated from category 8 (Knit Fabric Finishing of Cotton and Cotton/Synthetic Blends) due to characteristics and volume of the waste, i.e., use of different dyes and use of solvent scouring in category 9.

4.6.3.10 Category 10 – Piece Dyeing and Printing of Carpets of Wool, Cotton and Synthetics

This category covers the dyeing, printing and finishing of carpets of wool, cotton, or synthetics. Processing operations includes scouring, dyeing, printing and finishing or carpet. Wool carpets are also included in this category since they now comprise such a small percentage of the carpet business and because many carpet manufacturers produce both wool carpets and synthetic carpets.

4.6.3.11 Category 11 – Raw Stock and Yarn Dyeing of Cotton and Synthetic Fibers and Yarns

This category covers the scouring and dyeing of 100% cotton, cotton/synthetic blends and 100% synthetic fibers and yarns, and covers any stock or yarn dyeing operation performing these functions. Mercerizing of cotton yarns is included in this category since this operation in most cases is a part of the yarn dyeing and finishing operation.

4.6.4 Established Mill Waste Characteristics

In order to establish waste characteristics which represent each of the EPA categories, a comparison of results of both the ATMI and NCWQ studies has been made. Tables 4-32 thru 4-38 compare ATMI's average values and standard deviation to NCWQ's arithmetic mean values. It is noted that ATMI water use figures are generally higher than those reported in the NCWQ Survey. The values established for this manual are those judged to be reasonably representative of the specific category. It is these values which will be used in Chapter 7 to determine the percentage of pollutant removal required to meet effluent requirements and the treatment process most suitable.

TABLE 4-32

ESTABLISHED WASTEWATER CHARACTERISTICS

WOOL SCOURING MILLS
(EPA Category 1)

	ATMI		NCWQ	Use
	Avg.	Std. Dev.	Arith. Mean	
	mg/l	mg/l	mg/l	mg/l
BOD	3,700	3,600	5,500	6,000
TSS	6,600	2,500	7,500	8,000
COD	15,270	14,700	30,500	30,000
Oil & Grease	3,200	2,900	5,340	5,500
Total Chrome	—	—	0.05	0.05
Phenol	0.87	1.02	1.50	1.50
Sulfide	0.10	—	0.20	0.20
Color (ADMI)	—	—	2,000	2,000
Fecal Coliform	—	—	—	—
pH (Units)	7.23	0.46	6 - 9	8.0
Temp.	—	—	82°F	82°F
Water Use (gal/lb)	7.45	6.76	4.3	4.3

TABLE 4-33

ESTABLISHED WASTEWATER CHARACTERISTICS

WOOL FINISHING MILLS
(EPA Category 2)

	ATMI		NCWQ	Use
	Avg.	Std. Dev.	Arith. Mean	
	mg/l	mg/l	mg/l	mg/l
BOD	125	—	300	300
TSS	31	—	130	130
COD	—	—	1,041	1,040
Oil & Grease	—	—	—	—
Total Chrome	—	—	4	4
Phenol	—	—	0.5	0.5
Sulfide	—	—	0.1	0.1
Color (ADMI)	—	—	500-1700	1,000
Fecal Coliform	—	—	—	—
pH (Units)	6.92	—	6 - 11	7
Temp.	—	—	144°F	144°F
Water Use (gal/lb)	13.83	4.59	40*	40

* Based upon data for 6 mills as supplied by the Northern Textile Association

TABLE 4-34

ESTABLISHED WASTEWATER CHARACTERISTICS

DRY PROCESSING MILLS
(EPA Category 3)

	ATMI		NCWQ Arith. Mean	Use
	Avg.	Std. Dev.		
	mg/l	mg/l	mg/l	mg/l
BOD	274	123	300	350
TSS	87	163	150	200
COD	871	230	950	1,000
Oil & Grease	—	—	—	—
Total Chrome	8.65*	4.82*	—	.014
Phenol	—	—	—	—
Sulfide	8.00	—	—	8.0
Color (ADMI)	—	—	—	—
pH (Units)	11.53	5.78	6 - 11	10
Fecal Coliform	—	—	—	—
Temp.	—	—	70°F	70°F
Water Use (gal/lb)	1.51	1.52	1.5	1.5

*May be due to cooling tower discharges.

TABLE 4-35

ESTABLISHED WASTEWATER CHARACTERISTICS

WOVEN FABRIC FINISHING MILLS
(EPA Category 4)

	ATMI		NCWQ Arith. Mean	Use
	Avg.	Std. Dev.		
	mg/l	mg/l	mg/l	mg/l
BOD	592	392	550	650
TSS	313	533	185	300
COD	1,093	513	1,850	1,200
Oil & Grease	14	—	—	14
Total Chrome	4.3*	4.23	0.04	0.04
Phenol	.01	.01	0.04	0.04
Sulfide	2.72	4.57	2.72	3.0
Color (ADMI)	—	—	325	325
Fecal Coliform	—	—	—	—
pH (Units)	11.62	2.89	6-11	10
Temp.	—	—	99°F	99°F
Water Use (gal/lb)	18.14	9.93	13.5	13.5

*High value may be due to sulfur dyeing.

TABLE 4-36

ESTABLISHED WASTEWATER CHARACTERISTICS

KNIT FABRIC FINISHING MILLS
(EPA Category 5)

	ATMI		NCWQ	
	Avg.	Std. Dev.	Arith. Mean	Use
	mg/l	mg/l	mg/l	mg/l
BOD	335	303	250	350
TSS	115	123	300	300
COD	1,105	345	850	1,000
Oil & Grease	53	—	—	53
Total Chrome	—	—	0.05	0.05
Phenol	23.0*	—	0.24	0.24
Sulfide	—	—	0.20	0.20
Color (ADMI)	1,295	1,046	400	400
Fecal Coliform	—	—	—	—
pH (Units)	6.90	2.05	6-9	8
Temp.	—	—	102°F	102°F
Water Use (gal/lb)	20.05	9.77	18	18

*One sample mill only.

TABLE 4-37

ESTABLISHED WASTEWATER CHARACTERISTICS

INTEGRATED CARPET MILLS
(EPA Category 6)

	ATMI		NCWQ	
	Avg.	Std. Dev.	Arith. Mean	Use
	mg/l	mg/l	mg/l	mg/l
BOD	177	73	340	300
TSS	75	19	120	120
COD	852	584	925	1,000
Oil & Grease	—	—	—	—
Total Chrome	0.42	—	—	0.42
Phenol	0.13	—	—	0.13
Sulfide	—	—	—	0.14
Color (ADMI)	—	—	600	600
Fecal Coliform	—	—	—	—
pH (Units)	—	—	6-9	8
Temp.	—	—	67°F	67°F
Water Use (gal/lb)	7.5	4.7	8.3	8.3

TABLE 4-38

ESTABLISHED WASTEWATER CHARACTERISTICS

STOCK & YARN DYEING & FINISHING MILLS
(EPA Category 7)

	ATMI		NCWQ	
	Avg.	Std. Dev.	Arith. Mean	Use
	mg/l	mg/l	mg/l	mg/l
BOD	240	166	200	250
TSS	77	69	50	75
COD	882	733	524	800
Oil & Grease	—	—	—	—
Total Chrome	0.27	—	0.013	0.27
Phenol	—	—	0.12	0.12
Sulfide	—	—	—	0.09
Color (ADMI)	12	—	600	600
Fecal coliform	—	—	—	—
pH (Units)	8.93	2.60	7-12	11
Temp.	—	—	100°F	100°F
Water Use (gal/lb)	22.26	17.38	18	18

4.7 References

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CHAPTER 5

THE WASTE SURVEY

5.1 Introduction

One of the first major steps in an industrial water pollution control program is to define the scope of the abatement effort by determining the characteristics of the wastewater. This chapter deals with the wastewater characteristics, or wastewater-survey, segment of the pollution control program and also with a continuing survey to monitor changing characteristics and to aid in evaluating production changes.

The waste-survey topic can be broken into the following four essentially chronological segments:

- Preliminary survey
- Detailed survey
- Data evaluation
- Continuing monitoring

5.2 Preliminary Survey

The initial effort in a water-pollution-control program is typically a feasibility study that attempts to answer the following questions:

- What will be the discharge criteria?
- What are the likely methods of treatment?
- What in-plant alternates are available for waste reduction?

The data base for this feasibility study is the information gathered from a preliminary waste survey. The goals of this initial survey are to:

- Determine the approximate volume of wastewater
- Determine the approximate wastewater characteristics
- Define the major waste sources and possible methods of in-plant waste reduction and control
- Define the approximate characteristics of the raw-water source and the receiving stream (1).

The purpose of the survey, therefore, is not to define the problem for the purposes of final commitments, but only to obtain an accurate overview that will allow selection of the most likely problem solutions from the many that are available. The duration and complexity of this work will vary proportionally with the size and complexity of the mill and with the degree to which experience or the literature can provide direction or answers.

Any preliminary survey should consist of the following segments:

- Development of an approximate water and wastewater balance
- Wastewater sampling and analysis
- Review of manufacturing operations and raw material usage
- Flow measurement, sampling and analysis of major waste sources
- Sampling and analysis of the raw water and receiving stream

Incoming-water information for the mill can be developed from any of the methods shown in Table 5-1. Ideally, there will be water meters installed on the major branches of the mill-distribution system, but this is seldom the case, and an approximate breakdown of the water flow is usually necessary. These water data should cover several 1-month periods in order to reflect various production levels and product mixes. This water use should be broken down on a daily basis, and the production level for each area should be recorded. The final result of this work will be a drawing such as that shown in Figure 5-1, which indicates the distribution system, the water usage in gallons per day and the water usage rate in gallons per pound of cloth.

Similarly, a detailed map should be developed showing the location of major sewer lines and sources of wastewater. Process, sanitary and storm water sources should be indicated, as should be points of discharge.

Typically, most mills do not have an accurate drawing showing the locations of all sewer lines and waste sources, but it is important that this map be developed. Dye tracing should be used to identify what happens to all known sources and to check for cross-connections between separate sewer systems.

TABLE 5-1

METHODS OF FLOW MEASUREMENT FOR INCOMING WATER AND WASTEWATER

Water	Method
Incoming	Daily water-meter readings Monthly water bills Records of pump running time Estimations of capacity of water-use points
Waste	Discharge through an orifice Discharge over a weir Discharge through a flume Salt injection Dye or float timing Timing of a container Pump timing Current meters Venturi, orifice, or magnetic flow meters Rotameter

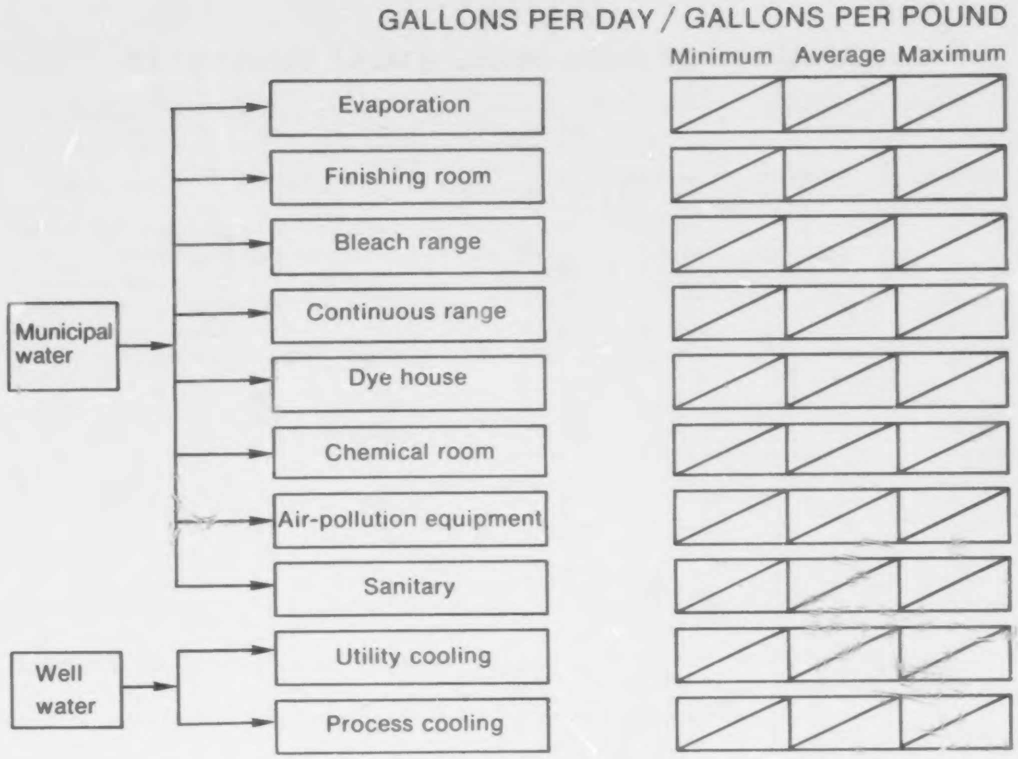

GALLONS PER DAY / GALLONS PER POUND
Minimum
Average
Maximum
Municipal water
Evaporation
Finishing room
Bleach range
Continuous range
Dye house
Chemical room
Air-pollution equipment
Sanitary
Well water
Utility cooling
Process cooling

FIGURE 5-1

WATER-DISTRIBUTION SYSTEM FOR A FINISHING PLANT

Flow rates for sanitary and storm water sources can be estimated, but flow rates for the process sewer or sewers should be determined by flow measurement. The method of flow measurement used is dependent on the volume of water, the physical restraints of the measurement point, and the accuracy required. Tables 5-1 and 5-2 and Figure 5-2 show the various methods of measuremen normally used and the conditions under which they are appropriate.

For a preliminary study, flows should be measured once per hour over a 24-hour period 1 day per week for 4 weeks. These data can then be compared with production and water-use data to extrapolate to various production levels.

The final result of this work will be a drawing such as that shown in Figure 5-3, which indicates the sewer system, the flow in gallons per day from the major waste sources, and the flow rate in gallons per pound of cloth from the major waste sources.

Simultaneous with the flow measurement, sampling of the wastewater should be accomplished. An automatic sampler station that will provide hourly samples is recommended. This equipment should allow for either continuous or intermittent sampling so that each hour sample will be a composite. Figure 5-4 shows various sampling equipment arrangements.

TABLE 5-2

COMPARISON OF FLOW-MEASUREMENT TECHNIQUES

Specific notes

Method	Flow range	Cost	Ease of installation	Accuracy	Application
Orifice	Small	Medium	Fair	Excellent	Pipe and open channel
Weir	Small to large	Medium	Fair to difficult	Good to excellent	Open channel
Flume	Small to large	High	Difficult	Excellent	Open channel
Salt injection	Small to medium	Low	Fair	Good	Pipe and open channel
Dye or float	Small	Low	N/A	Fair	Open channel
Container	Small	Low	N/A	Good	Pipe and open channel
Pump	Small to large	N/A	N/A	Fair	Pipe
Current meters	Small to large	Medium	Fair	Fair	Pipe and open channel
Flow meters	Small to large	High	Difficult	Excellent	Pipe
Rotameter	Small to medium	Medium	Fair	Good	Pipe
Open end pipe	Small to medium	Low	Fair	Fair	Open channel

General notes

Method	Notes
Orifice	An orifice can be used to determine the flow from a vessel through a circular outlet by measuring the height of water in the vessel.
Weir	A weir is used to determine flow by measuring the difference in elevation between the discharge edge (crest) and the upstream water level. Weirs are simple, reliable measurement devices when they are installed correctly. Accuracy is ±5 percent. • The weir crest must be sharp • Air must have access to the underside of the falling water • Leaks must be sealed • Weir must be exactly level • Weir approach must be kept clean of sediment • The head should be measured back of the crest at least five times the height • The upstream channel should be reasonably free from disturbances • A weir measurement should consist of the average of several equally timed readings There is more head generated on a V-notch weir; therefore, these weirs are used for smaller flows in order to maintain accuracy. Automated level recorders (pressure or mechanical) should be used for permanent installations or deep sewers. A Parshall flume is a permanent installation that measures the difference in water levels caused by a constriction in the channel cross section. The advantage of dependable accuracy, low head loss, and large capacity range are offset by the high installation costs. The flume can be purchased as a complete package with flow recording equipment. An accuracy of ±5 percent is obtained when the equipment is installed properly. • Standard dimensions must be used • The downstream head should not exceed the recommended percentage of upstream head • The upstream head is measured in a stilling well • The flume is installed in a straight channel, and there is no close upstream turbulence

(Continued)

TABLE 5-2 (Continued)
COMPARISON OF FLOW-MEASUREMENT TECHNIQUES

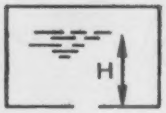
General notes	
Method	Note
Salt injection	The salt injection method depends on determining the downstream concentration of a readily detectable chemical (e.g. lithium chloride) when a known quantity of the material is injected upstream. The method is useful when: • The physical location of the sewer (e.g., depth) makes weir measurement impossible • Waste is flowing under pressure • Accurate total flow values are required, and mechanical or frequent manual weir height measurement is not feasible • A simultaneous sampling is being conducted
Floats	This method requires the measurement of water depths and velocity and should only be used for approximations of flow.
Container	This method requires measuring the time for a discharge to fill a vessel of known volume and is good only for small flows.
Pump	This method requires timing the amount of time a pump is running and determining the water volume from the pump characteristics. It should only be used for approximations of flow.
Current meters	This method requires determining the cross sectional area of a channel and measuring the water velocity in several segments. The method is used for measuing small stream flows.
Flow meters	Flow meters measure water flow in pressure systems by detecting differential pressure across a contraction (e.g., Venturi tube or orifice plate) or by detecting the electrical potential produced by the flow. This equipment is accurate and reliable over a wide range of flows but is an expensive, permanent installation.
Rotameters	These meters measure water flow by the water turning a set of gears to totalize flow or by suspending a float to indicate instantaneous flow. The equipment will vary widely in cost depending on size and accuracy requirements.
Open-end pipe	This method requires the measurement of vertical fall of a free-flowing discharge from a pipe and should only be used when other methods are not practicable.

The test methods recommended by the EPA in the June 29, 1973, Federal Register are summarized in Table 5-3.

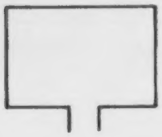
At the end of a 4-hour period, the hourly samples should be chemically preserved and refrigerated unless analyzed immediately. Table 5-4 shows the preservation procedures recommended by the EPA. The EPA *Methods of Chemical Analysis of Water and Wastes* is recommended as the procedural standard. Figure 5-5 shows the results of a flow and sampling survey.

The analytical schedule for the process sewer samples is dictated by the discharge criteria and by a knowledge of manufacturing chemicals. EPA and the States require the filing of a permit application for obtaining a discharge permit under the 1972 amendments. This application requires information on some 60 parameters. In order to limit the extent of the analysis program, it is recommended that the schedule shown in Table 5-5 be used for the preliminary survey.

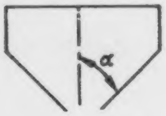
The work discussed above is to develop the information necessary for final treatment of the wastes. Of equal importance is the in-plant analysis to define major sources and possible methods of waste reduction and/or segregation. This work is started by developing 1) a material balance for each major production unit and 2) a history of chemical and dyestuff usage.



c = 0.632



c = 0.966

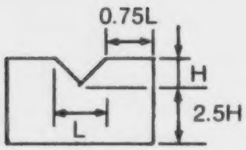


$$Q = cA\sqrt{2gH}$$

Q = discharge, ft³/s
c = constant
A = orifice area, ft²
V = velocity, ft/s
g = acceleration due to gravity, ft/s² = 32.2
H = head, ft

α =	67½°	45°	22½°
c =	0.684	0.753	0.882

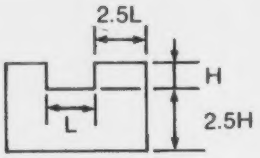
A. ORIFICE



90° V Notch

$$Q = 2.52H^{2.47}$$

Q = discharge, ft³/s
H = head, ft



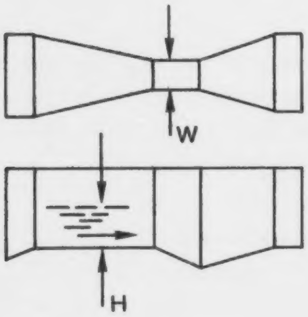
Rectangular Weir

$$Q = 3.33LH^{1.5}$$

Q = discharge, ft³/s
H = head, ft
L = length of weir, ft

1. $H < 1/3\ L$
2. $0.5 < H < 2.0$
3. approach velocity less than 1 ft/s

B. WEIRS



$$Q = 4WH^{n}$$

Q = discharge ft³/s
W = throat width, ft
H = head, ft
$n = 1.522W^{0.026}$

C. PARSHALL FLUME

FIGURE 5-2

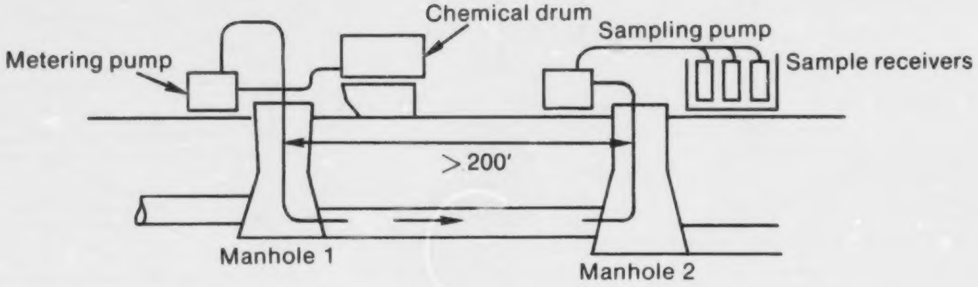
FORMULAS FOR FLOW MEASUREMENT BY VARIOUS DEVICES

(Continued)

$$Q = A'k\,(D/T)$$

Q = discharge, ft^3/s
A' = wetted cross sectional area of sewer ft^2
D = distance between manholes, ft
T = average time, s
K = 0.8 for floats and 1.0 for dyes

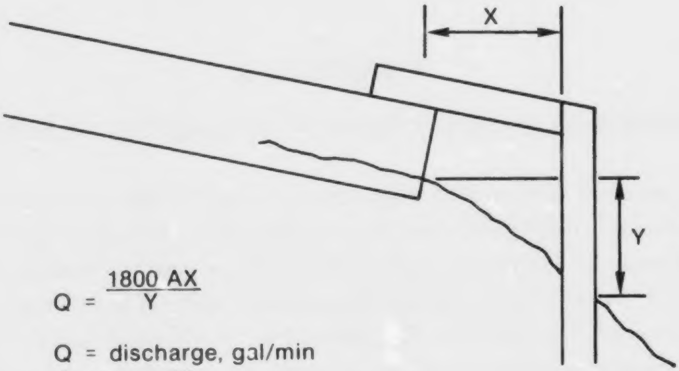
D. FLOATS


Chemical drum
Sampling pump
Metering pump
Sample receivers
> 200'
Manhole 1
Manhole 2

$$Q = \frac{Q_t(C_t - C)}{C}$$

Q = discharge, ft^3/s
Q_t = discharge of tracer
C = concentration of tracer in water after injection
C_t = concentration of tracer being injected

E. CHEMICAL TRACERS



$$Q = \frac{1800\,AX}{Y}$$

Q = discharge, gal/min
A = area, ft^2
Y = distance from water level in pipe to water level in stream at X, ft.

F. END OF PIPE

FIGURE 5-2

(Continued)

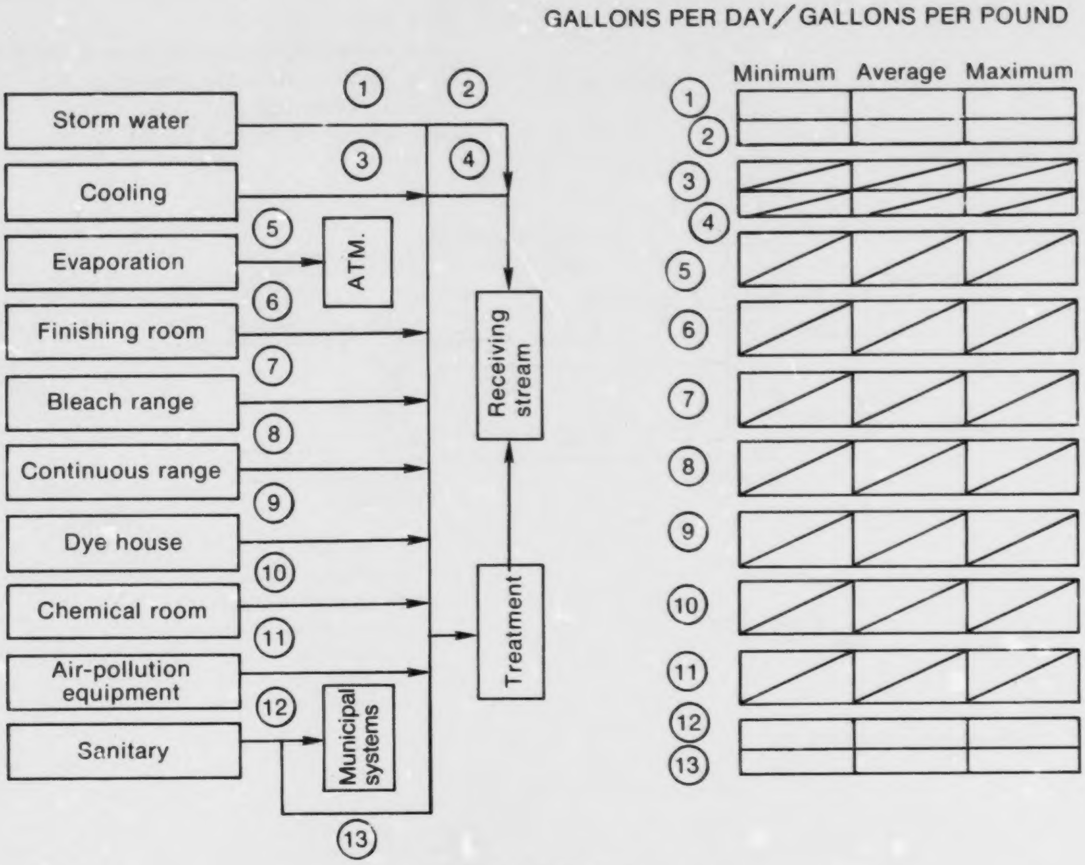

GALLONS PER DAY/GALLONS PER POUND
Minimum
Average
Maximum
Storm water
Cooling
Evaporation
Finishing room
Bleach range
Continuous range
Dye house
Chemical room
Air-pollution equipment
Sanitary
ATM.
Municipal systems
Receiving stream
Treatment
①
②
③
④
⑤
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬

FIGURE 5-3

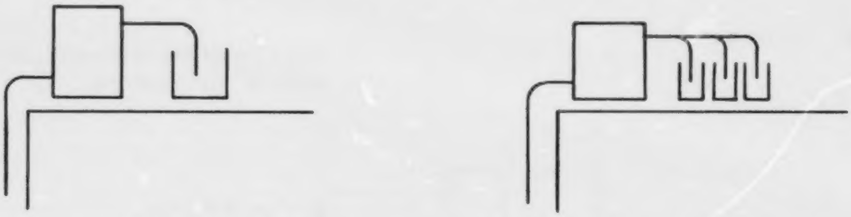
SEWER-SYSTEM SCHEMATIC FOR WASTE SURVEY

The intent of the material balance is to indicate both the fabric and chemicals going into and out of a production unit. It is typical that the concentration of the chemicals coming from a production unit cannot be readily determined. Therefore, at least the wastewater characteristics should be indicated. The vendors of chemicals used in the mill can be of help in determining effluent concentrations of their materials. Examples of this work are shown in Figures 5-6 and 5-7 and Table 5-6. The material balance analysis also serves as a check on process efficiency and may indicate potential cost-saving changes.

The intent of the analysis of chemical and dyestuff usage is to approximate the chemical nature of the wastewater. As in the case of the water balance, at this stage only one or two representative months need to be examined. The form of this analysis can be as that shown in Table 5-7 and will indicate the importance of various chemicals to the treatment system. As part of the in-plant sampling and analysis program, an analysis of the wastewater characteristics of the major chemicals at various concentrations may be made. The data, when combined with a knowledge of the concentration in the effluent, will help to evaluate the treatment alternatives.

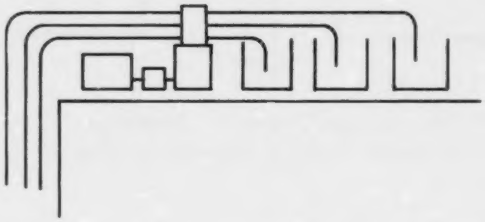
Types of Samples

- Grab: A single, manually collected sample
- Continuous: A single sample or a series of samples taken over a period of time by either
  - —A continuous small volume of flow
  - —An intermittent small volume of flow
  - —An intermittent small "Cut" of a larger volume of flow
- Composited: A single sample made up of flow-proportional amounts of several individual samples. The sample may be either a grab or a continuous composite.

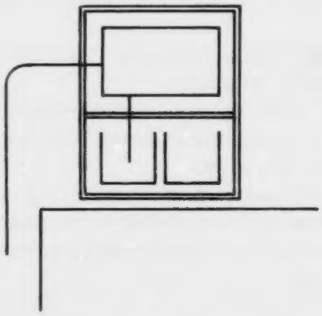


A. Portable, self-contained sampling unit, variable speed, on/off flow, single composite

B. Same as "A" but with hourly compositor



C. Multiple-head, variable-speed pump with on/off flow for semipermanent installation

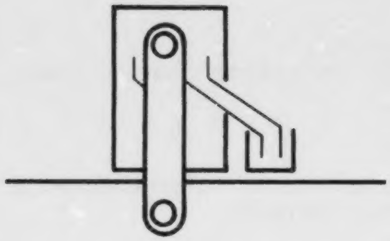


D. Self-contained sampling unit with refrigeration unit

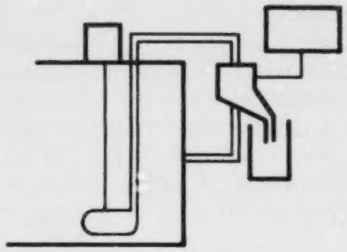
FIGURE 5-4

SEVEN TYPICAL METHODS OF SAMPLING WASTES

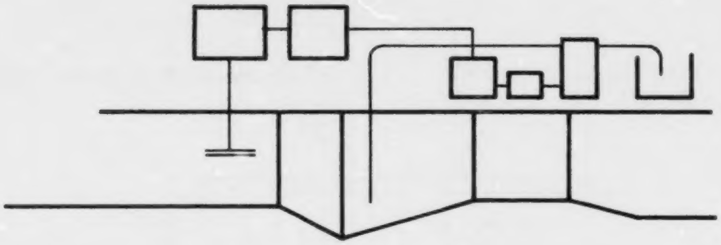
(Continued)



E. Dipper sampler



F. Mechanical sampler with pump to obtain a "split" or "cut" sample



G. Permanent flow and sample station consisting of a flow recorder, transmitter, variable-speed pump, and pump timer mounted over a Parshall Flume

General notes:

- The sample point should be at approximately one-third of the water depth for sewers and channels.
- Sampling point should not be adjacent to turbulent area, but flow should be mixed to insure representative sampling, particularly of solids.
- Tube size and sample velocity should be considered to insure proper handling of solids.
- Flow variations can normally be adequately covered with a sampling frequency of 10-15 minutes unless the variations are very large.
- For suction lifts of greater than 12 feet, submersible pumps should be used.
- Sample containers should be glass or inert plastic and adequately washed after being emptied.
- For winter sampling, tubing should be placed in heat-traced pipes and sampler placed in a box with a heat lamp or heat pad.

FIGURE 5-4

(Continued)

TABLE 5-3

TEST METHODS RECOMMENDED BY THE EPA

Measurement	Reference[1]
Alkalinity	C, p. 6
Ammonia nitrogen	C, p. 134
Arsenic	A, p. 65, 4A (digestion) A, p. 62, method 104A (measurement)
Boron	A, p. 69
Cadmium	C, p. 83
Chloride	B, p. 21, method A
Chromium	C, p. 83
Conductance specific	B, p. 162, method B
Copper	C, p. 83
Fluoride	A, p. 171, method 121A with p. 174, method 121C
Hardness	A, p. 179, method 122A
Iron	C, p. 83
Magnesium	C, p. 83
Manganese	C, p. 83
Mercury	D
Nitrate nitrogen	A, p. 458, method 213B
Nitrogen, total Kjeldahl	A, p. 469, method 216
Organic carbon, total	C, p. 221
Organochlorine pesticides	D, Appendix A, Part II
Orthophosphate	C, p. 243
Oxygen demand, biochemical	A, p. 489, method 219
Oxygen demand, chemical	A, p. 495, method 220
Phosphorus, total	C, p. 242
Selenium	A, p. 296, method 150A
Silver	C, p. 83
Solids, total	A, p. 535, method 224A
Surfactants	A, p. 559, method 229
Suspended nonfilterable solids, total	A, p. 537, method 224C
Temperature	A, p. 559, method 162
Zinc	C, p. 83

[1] "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 13th edition, 1971. This publication is available from the American Public Health Association, 1015 18th St., NW., Washington, D.C. 20036.

"B" refers to the *Annual Book of Standards*, Part 23, Water; Atmospheric Analysis, 1972. This publication is available from the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

"C" refers to *Methods for Chemical Analysis of Water and Wastes*, Environmental Protection Agency, Analytical Quality Control Laboratory, Cincinnati, Ohio. This publication is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock no. 5501-0067).

"D" refers to *National Pollutant Discharge Elimination, appendix A, Federal Register, 38, No. 75, pt. II.*

TABLE 5-4
SAMPLE PRESERVATION REQUIREMENTS FOR VARIOUS PARAMETERS

Parameters	Preservative	Maximum holding period
Acidity-alkalinity	Refrigeration at 4°C	24 hours
Biochemical oxygen demand (BOD)	Refrigeration at 4°C	6 hours
Calcium	None required	7 days
Chemical oxygen demand (COD)	2 ml H_2SO_4 per liter	7 days
Chloride	None required	7 days
Color	Refrigeration at 4°C	24 hours
Cyanide	NaOH to pH 10	24 hours
Dissolved oxygen	Determine on site	No holding
Fluoride	None required	7 days
Hardness	None required	7 days
Metals, total	5 ml HNO_3 per liter	6 months
Metals, dissolved	Filtrate: 3 ml 1:1 HNO_3 per liter	6 months
Nitrogen, ammonia	40 mg $HgCl_2$ per liter—4° C	7 days
Nitrogen, Kjeldahl	40 mg $HgCl_2$ per liter—4°C	Unstable
Nitrogen, nitrate-nitrite	40 mg $HgCl_2$ per liter—4°C	7 days
Oil and grease	2 ml H_2SO_4 per liter—4°C	24 hours
Organic carbon	2 ml H_2SO_4 per liter (pH 2)	7 days
pH	Determine on site	No holding
Phenolics	1.0 g $CuSO_4$/1+H_3PO_4 to pH 4.0—4°C	24 hours
Solids	None available	7 days
Specific conductance	None required	7 days
Sulfate	Refrigeration at 4°C	7 days
Sulfide	2 ml Zn acetate per liter	7 days
Threshold odor	Refrigeration at 4°C	24 hours
Turbidity	None available	7 days

Source: *Methods for Chemical Analysis of Water and Wastes*, EPA, 1971.

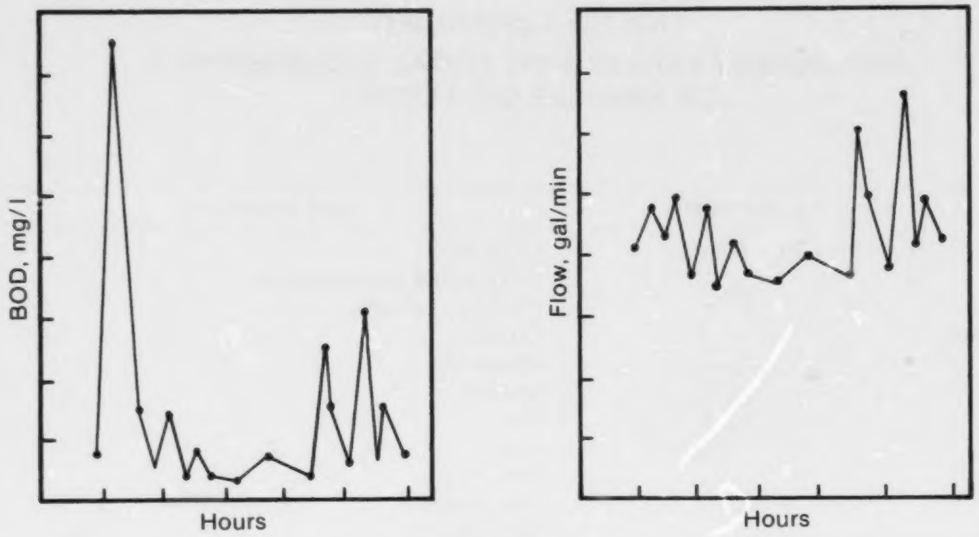


FIGURE 5-5

TYPICAL PRELIMINARY SURVEY RESULTS OF BOD AND FLOW MEASUREMENTS AS A FUNCTION OF TIME

TABLE 5-5

PRELIMINARY SURVEY ANALYTICAL REQUIREMENTS ON SAMPLES COLLECTED

First set of samples	
Time of measurement	Item measured
Time-of-flow measurement	Dissolved oxygen
	Temperature
Hourly	BOD
	COD
	Suspended solids
	pH
	Color
	Alkalinity
24-hour composite	Dissolved solids
	Various forms of nitrogen
	Phosphorus
	Turbidity
	Various forms of sulfur
	Halogens
	Cyanide
	Phenol
	Surfactants
	Aluminum
	Arsenic
	Cadmium

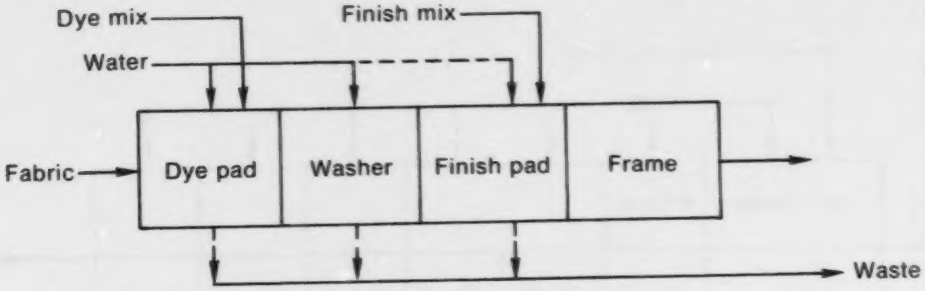
(Continued)

TABLE 5-5 (Continued)

PRELIMINARY SURVEY ANALYTICAL REQUIREMENTS ON SAMPLES COLLECTED

Time of measurement	Item measured
24-hour composite—*Continued*	Calcium
	Chlorinated hydrocarbons
	Coliform bacteria
	Cobalt
	Chromium
	Copper
	Iron
	Lead
	Magnesium
	Manganese
	Mercury
	Nickel
	Potassium
	Zinc
Second, third, and fourth set of samples	
Instantaneous and hourly	Same as first set
24-hour composite	Dissolved solids
	Forms of nitrogen ($p > 0.1$)
	Phosphorus
	Turbidity
	Forms of sulfur ($p > 0.1$)
	Halogens found ($p > 0.1$)
	Cyanide ($p > 0.01$)
	Phenol
	Surfactants
	Aluminum ($p > 1.0$)
	Arsenic ($p > 0.01$)
	Cadmium ($p > 0.01$)
	Calcium ($p > 10$)
	Cobalt ($p > 0.01$)
	Chromium
	Copper
	Iron
	Chlorinated hydrocarbons ($p > 0.01$)
	Coliform bacteria ($p > 1000$);
	Lead ($p > 0.01$)
	Magnesium ($p > 10$)
	Manganese ($p > 1$)
	Mercury ($p > 0.001$)
	Nickel ($p > 0.001$)
	Potassium ($p > 10$)
	Zinc

Note.—The shorthand ($p>0.01$) indicates that further analysis is necessary only if the first analysis indicates a value greater than 0.01 mg/l.


Dye mix
Finish mix
Water
Fabric
Dye pad
Washer
Finish pad
Frame
Waste

	Dye pad	Washer	Finish pad	Equipment wash
pH				
BOD				
COD				
Color				
Flow				

Dye formulas ____________
____
____

Finish formulas ____________
____
____

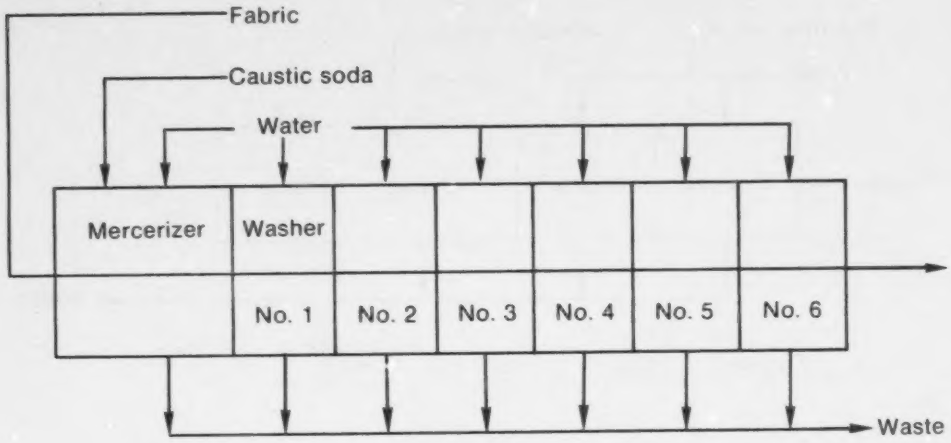
Products ____________
____

Product rate ____________

Miscellaneous chemicals ____________

FIGURE 5-6

DYE-RANGE MATERIAL BALANCE



Alkalinity

Fabric						
Waste						

Fabric production rate: ______

Total water use: ______

Total caustic use: ______ Concentration: ______

FIGURE 5-7

MERCERIZER AND WASHER MATERIAL BALANCE

TABLE 5-6

LIST OF IMPORTANT ITEMS FOR TEXTILE IN-PLANT SURVEYS

Identification of print paste, grease, and solvent wastes for segregation to separate treatment
Identification of sources of chemicals potentially toxic to activated sludge systems (such as dyes, solvents, carriers, or finishes)
Identification of sources of shock loads (such as finishing bath dumps)
Identification of sources of high concentrations of refractory, nonbiodegradable wastes (such as carriers and finishes)
Identification of sources of foam-producing chemicals (such as detergents)
Evaluation of size substitutions
Optimization of countercurrent washes
Evaluation of reuse of weak rinse wastes
Evaluation of segregation of high strength (such as BOD, COD, color, or alkalinity) for separate treatment
Evaluation of processing of caustic wastes for reuse
Evaluation of segregation of dyestuffs (acid, disperse, etc.) for separate treatment
Comparison of hypochlorite and hydrogen peroxide bleaching

TABLE 5-7
EXAMPLE OF ANNUAL CHEMICAL USAGE, 1972

Rank	Chemical (type)[1]	Usage	
		Pounds	Percent
1	Carrier NT (B)	331,457	12.540
2	Neutrol #9 (C)	200,064	7.569
3	Aerotex water repellant 95 (D)	136,205	5.153
4	Cap LEV LSP (C)	132,685	5.020
5	Soap OFF 60 (A)	126,708	4.794
6	Acetic acid (E)	124,206	4.699
7	Neoport APO (B)	117,609	4.449
8	Solvecrest RB (A)	110,788	4.191
9	Monosodium phosphate (E)	92,672	3.506
10	Caustic soda (E)	89,673	3.393
11	Dispersing agent (C)	84,887	3.212
12	Avitone F (C)	72,443	2.741
13	Calgon (F)	69,130	2.615
14	Fanapon X70 (A)	58,198	2.202
15	Neoport DPG (B)	51,871	1.962
16	Raycofix NY (H)	48,428	1.832
17	Sanopan DTC (A)	47,227	1.787
18	Formic acid (E)	46,779	1.770
19	Sodium hydrosulfite (A)	45,983	1.740
20	Cap Carrier BB (B)	38,867	1.470
21	Ammonium chloride (E)	38,189	1.445
22	Herriton SWD (C)	36,698	1.388
23	Intrawite EBF (G)	30,242	1.144
24	Gluconic acid (C)	27,416	1.037
25	Tanalube RF (C)	24,654	0.933

[1] A=scour; B=carrier; C=dyeing assistant; D=finish; E=pH control chemicals; F=softener; G=fluorescent; H=fixing.

For in-plant sampling, the use of appropriately chosen grab samples is usually sufficient. These samples should be taken during each part of the production cycle, and an estimate or measurement of flow should be made. Important wastewater characteristics should be measured in each sample, but it is not necessary to perform a full analysis of each sample.

Also, on the day that the process sewers are sampled, a single grab sample should be obtained from the receiving stream and the raw waste for complete analysis.

It should be apparent at this point in the review of the waste survey requirements that there is a significant analytical load to any meaningful survey and that there is a strong emphasis on in-plant production analysis.

Considering the degree of treatment being required of the textile industry, an important key to compliance will be a competent water-quality laboratory to provide both operating and reporting data. If a plant does not have sufficient facilities or staff for this work, then serious thought should be given to acquiring the capability on this early stage to assure maximum familiarity with the wastewater problem. This decision can usually be economically justified in light of outside laboratory costs.

Also, the importance of introducing responsible production personnel at the onset of the water-pollution-control program cannot be understated. This becomes even more important as regulations require consistent removal of virtually all pollutants from the discharge. Soliciting process information and keeping the production personnel informed of the work under way is the best way to develop a program of optimum waste reduction and recycling and to determine how the waste is affected by the operating characteristics of the process and its susceptibility to upset, misoperation and change.

5.3 Detailed Survey

After completion of the initial feasibility study, a decision will probably be made to evaluate, over a period of time, the treatment processes and in-plant control measures selected as the most likely solutions. This additional detailed process evaluation survey is necessary to establish the process design parameters firmly and should also be utilized to gather additional waste characterization and in-plant data.

Ideally, this final survey program should last 1 year in order to observe seasonal variations and production vagaries and to allow time to develop and explore alternatives fully. The elements of this detailed survey are essentially the same as the initial survey, but the intensity, duration and precision of the various aspects have increased.

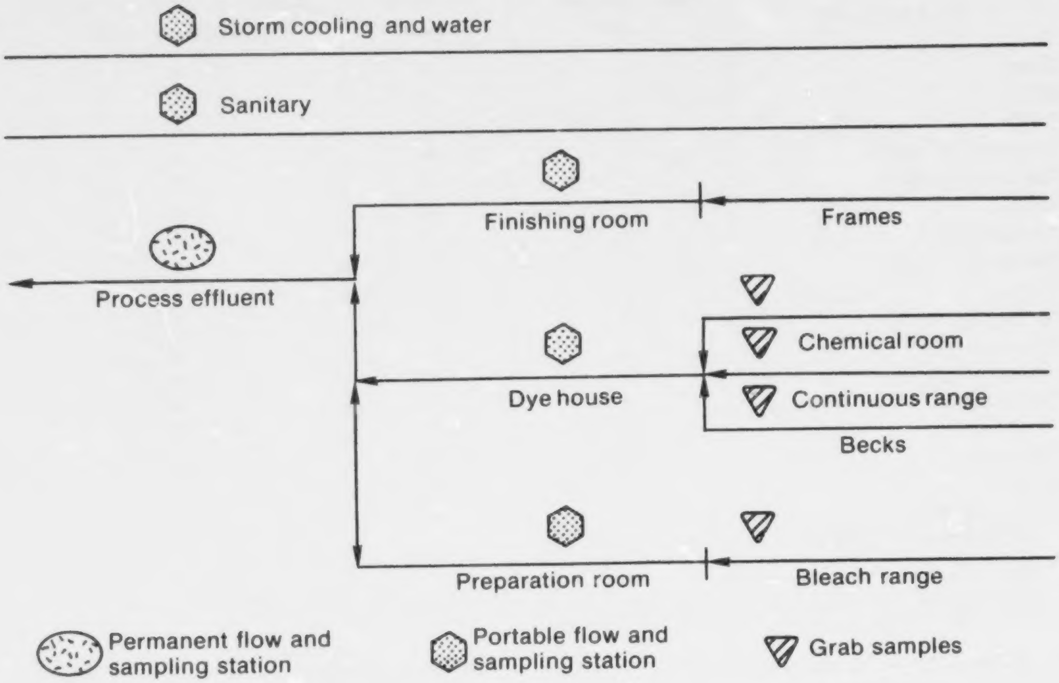
The incoming water balance information should continue to be recorded. Water meters will allow for daily measurements. These data should be reported both as gallons per day and gallons per pound of cloth. Similarly, refinement of the sewer balance should be undertaken.

At least one permanent flow measurement station should be built for a continuous record of total plant effluent volume on a daily basis. This equipment should provide a 24-hour graph of flow. If the wastewater volume can justify the expense, multiple stations should be installed to measure flow from each department or division. An example of station locations is shown in Figure 5-8.

As part of this station, a permanent sampling station should be installed to provide a single daily-flow composited sample. Periodically, this composite can be removed once every hour to evaluate variations in waste strength.

FIGURE 5-8

DETAILED SURVEY SAMPLING POINTS


Storm cooling and water
Sanitary
Finishing room
Frames
Process effluent
Chemical room
Dye house
Continuous range
Becks
Preparation room
Bleach range
Permanent flow and sampling station
Portable flow and sampling station
Grab samples

A program of daily analysis of the process sewer waste should be instituted. This program should attempt to frequently monitor critical wastewater characteristics and to regularly measure all necessary characteristics. A recommended analytical schedule is presented in Table 5-8.

Both flow and contaminant data should be reviewed frequently to determine trends and to change the direction of the work as required.

Production data should also be recorded during this period. A history of chemical and dyestuff usage should be maintained on a monthly basis. A history of production volume by major product lines should be maintained on a weekly or daily basis. Changes in production chemicals or processes should be noted.

Sampling and analysis of both raw water and receiving-stream water should continue once every 2-4 weeks. Raw-water samples should be taken on days when complete sewer analyses are scheduled.

If possible, any planned segregation of sewers should be accomplished during the study to make sure that valid data are obtained. Frequently, paper "substations" are not duplicated in the field because complete segregation is not always possible.

TABLE 5-8
DETAILED SURVEY ANALYTICAL SCHEDULE

Characteristic	Main process sewer	In-plant sewer	Cooling, sanitary, raw, and stream water
Flow	0	3	4
BOD	2	4	4
COD	2	3	4
Suspended solids	2	4	4
Dissolved solids	3	4	4
pH	2	4	4
Temperature	1	4	4
Dissolved oxygen	1	4	4
Color	2	4	4
Turbidity	3	4	4
Nitrogen	3	4	4
Phosphorus	3	4	4
Detergent	3	4	4
Phenols	3	4-5	5
Alkalinity	2-4	4-5	4-5
Metals	3-4	4-5	5
TOC[1] (or other instrumented method)	4	4-5	5

TOC[1] indicates total organic carbon.

Note.—0: measured daily; 1: measured in place; 2: measured 3 times per week; 3: measured 1 time per week; 4: measured 2 times per month; 5: measured 1 time per month.

The in-plant survey portion of the detailed survey is critically important. At this point, a significant amount of time should be spent reviewing the environmental impact of each waste source and each major chemical used.

It is especially valuable to observe production machinery under various conditions to determine the validity and variability of the data being collected and to determine the impact of problems and malfunctions, since these usually result in higher waste loadings.

This is the time to scrutinize each segment of each production process to determine if the minimum amount of water and chemicals are being used. Also, alternate chemicals need to be evaluated to determine if production goals can be met with a lower environmental impact. The production machinery itself should be reviewed to determine if the cost of alternate equipment would offset the cost of treating the pollutants generated. It is helpful at this point to begin to break down the projected water-pollution-control cost by department to make economic justification of charges easier to determine.

This is also the time to police the plant to eliminate unnecessary uses of water and to institute a program of prevention of accidental pollution. Typical examples are presented in Table 5-9.

As in the case of sewer segregation, any significant process changes should be made during the course of the study to insure that accurate and updated data are obtained.

TABLE 5-9

LISTING OF MISCELLANEOUS POLLUTION SOURCES

Eliminate running hoses.

Replace or repair leaking pumps, compressors, heat exchangers, or other similar equipment.

Install water meters and level controls on process equipment to minimize water use.

Dike chemical storage areas and make sure chemical-handling equipment is designed to minimize accidental spillage.

Institute dry clean up of dry-chemical spills.

Institute a reporting system for chemical spills and other extraordinary discharges to the plant sewer system.

Evaluate wet air-pollution equipment for change to dry equipment.

Evaluate maintenance and equipment-cleaning chemicals for pollution potential.

Evaluate boiler and cooling tower chemicals for pollution potential.

At the completion of the detailed survey, a sound foundation exists for establishing the basis for a treatment system design. The longer the detailed survey, the more variation in wastes will be seen. This information on variation is critically important. The treatment plants that will be required to meet new standards will have to achieve very high performance standards. Yet, unlike other typical chemical processes, there is limited control over the raw material to this plant.

5.4 Data Evaluation

With an accumulation of data, the evaluation of the data is done statistically. Probability and daily pollutant load curves, similar to those shown in Figure 5-9, allow for the interpretation of this large volume of information.

Wastewater data should be evaluated not only by themselves, but also in terms of the production. Data should be presented as gallons or pounds per unit of total production. If possible, production data should be broken down into major categories and a computer correlation should be made with daily wastewater data broken down to give gallons or pounds per unit of each product line or production area.

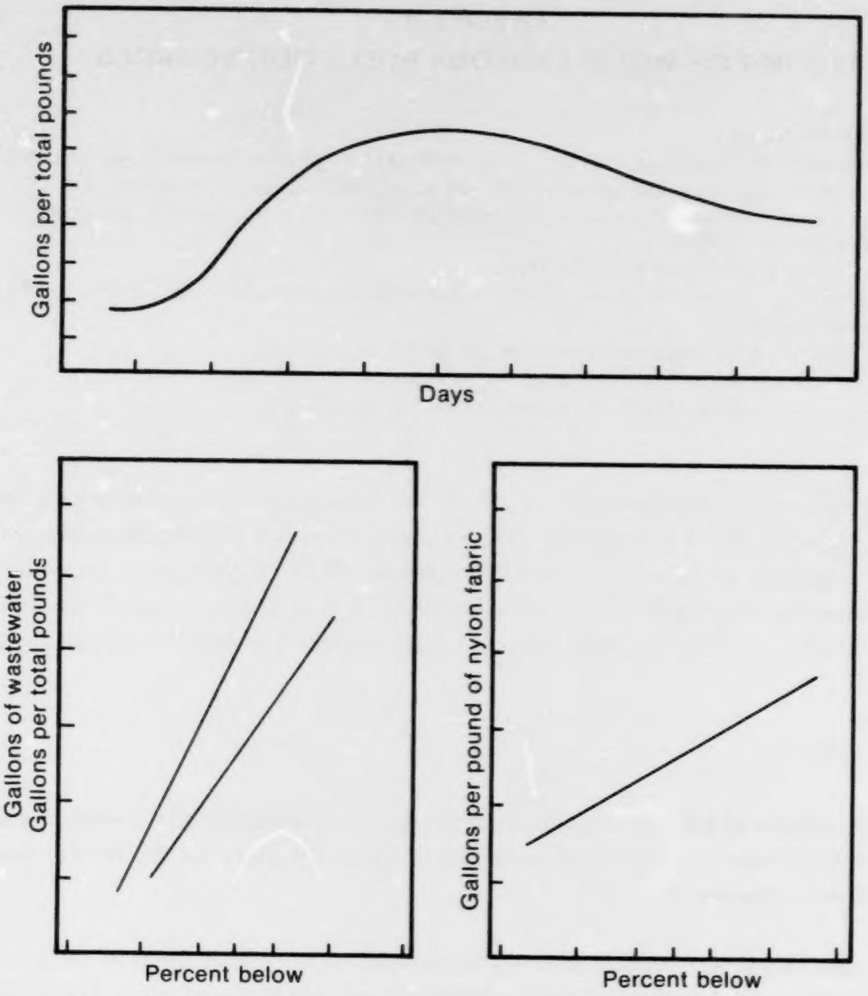


FIGURE 5-9

GRAPHICAL RESULTS OF DETAILED SURVEY

The data collected should also be interpreted in terms of the production processes and chemicals used, and separate evaluations should be made, when possible, for the various periods.

The final step in the data evaluation segment is to correlate the information on present operation with the estimated capacity of the present or future manufacturing facility. The more production segments that can be used to compile the estimate, the better the validity of the design basis.

5.5 Continuing Monitoring

In addition to providing the basis for a rational wastewater-treatment-system design, the information collected during the detailed survey will serve as a standard in monitoring the treatment facility for operational purposes and in comparing alternate production methods and chemicals.

The importance of involvement of production personnel is strongly emphasized. Each supervisor should be aware of his department's portion of:

- The pollutants in pounds per pound of product
- The flow in pounds per pound of product
- The treatment cost in pounds per pound of product
- The environmental effect of production upsets
- The environmental impact of major production chemicals

Since textile mills are users of a wide variety of chemicals and since product lines regularly change, there is a continual change in the chemicals found in the sewer. It is imperative that in addition to production characteristics, the environmental characteristics be considered in evaluating a new chemical. During the detailed survey, the pollution potential should be determined for important chemicals. In the continuing survey, these characteristics are recorded for all chemicals. Also in the detailed survey, brief treatability studies on the major chemicals may have been done; this work should be continued. An example of the data that might be collected is given in Figure 5-10. This information will serve as a standard for comparing alternate chemicals.

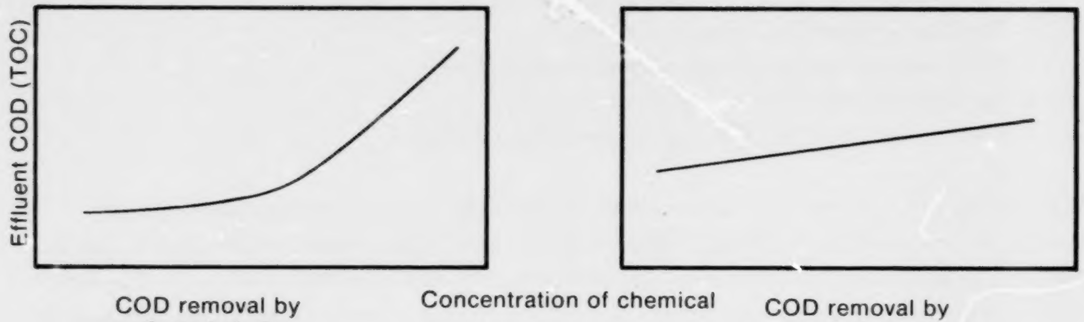
Continuing monitoring is incomplete without an analysis of the impact of the discharge on the receiving stream. First, stream flow records should be obtained from the U.S. Geological Survey in order to develop critical flow values for various periods during the year. Second, information on quantity and location should be gathered on users of and dischargers to the receiving stream. Third, the receiving water should be completely analyzed, with single, representative grab samples of water above the discharge should be obtained when the process sewers are sampled. Finally, a single sample of bottom deposit above the discharge should be obtained for examination for basic indicator organisms and for chemical analysis. This later work will indicate the present condition of the stream and its tolerance to additional pollutants.

The advent of industrial discharge criteria would seem to obviate the need for consideration of the effect on the receiving stream, but it should be remembered that many States have or are developing stream criteria that may be more stringent than the Federal guidelines. This is especially important when the discharge is to a stream rather than a large river.

In addition to the upstream sampling and analysis of receiving stream water, a profile of the receiving stream at various stages below the discharge should be examined. This profile should consist of both chemical and biological analysis of the water and the sediment and will serve as a baseline of the stream's condition against which the new charge can be compared. A single bioassay and multiple chemical assays will be necessary for accurate results. Also, static toxicity studies using local species of fish and expected effluent should be performed to determine maximum allowable pollutant concentrations and to verify design discharge criteria.

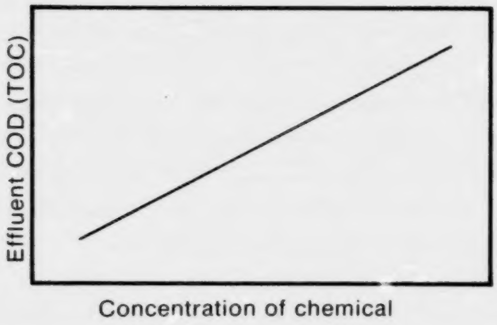
Finally, the continuing survey should monitor individual processes to make sure that unnecessary amounts of water and chemicals are not being used. That is, environmental impact should become a tangible part of the industrial engineering function of process optimization.

COD (TOC) of 1.0% solution: ____________________



COD removal by activated sludge at MLSS of 3,000 mg/l

COD removal by coagulation with 400 mg/l alum



COD removal by carbon adsorption with 3.0 lb/1,000 gal

FIGURE 5-10

TYPICAL DATA FOR DETERMINING TREATABILITY OF PROCESS CHEMICALS

5.6 References

1. U.S. Environmental Protection Agency, Technology Transfer, *In-Plant Control of Pollution, Upgrading, Textile Operations to Reduce Pollution:* Chapter 1, Waste Survey, October, 1974.

CHAPTER 6

IN-PLANT WASTEWATER CONTROLS

6.1 Waste Volume Reduction

It is obvious that the more wastewater volume is reduced in processing, the less water will have to be treated at the waste treatment plant. Indeed,with all the more pressing production cost savings, it is sometimes difficult to stop and look at the advantages of reducing water usage. However, as the price of treated water continues upwards, along with the price of waste treatment, priorities will change and increasingly favor water conservation.

6.1.1 Previous Studies

Numerous studies have been carried out which indicate water usages by industrial subcategory and process, but no obvious relationships are seen to exist between processes to indicate specific water uses in gal/lb, and the total quantity of water used. Smaller companies in general show lower water usage per pound of fabric, but there are also some with usages above the average. Plants in the same subcategory that carry out many processes will obviously use more water per pound of product than those performing fewer. Those processing heavier weight fabrics may use more water than those processing lightweight goods. In other words, the complexity of processing and fabric weight are major factors determining water usage.

The following Tables 6-1, 6-2, and 6-3, indicate water usages in wool, cotton and man-made fiber processing. These tables should be regarded as estimates of water use, due to lack of accurate flow measurement and small samplings.

Refer to Chapter 4 for an understanding of the processes listed.

TABLE 6-1

WATER USAGE OF WOOL WET PROCESSES

Process	Volume in gal/1000 lb product
Scouring	5,500 - 12,000
Dyeing	1,900 - 2,680
Washing	40,000 - 100,000
Neutralization	12,500 - 15,700
Bleaching	300 - 2,680

TABLE 6-2
WATER USAGE OF COTTON WET PROCESSING WASTE

Process	Volume in gal/1000 lb product
Slashing, sizing yarn[1]	60 - 940
Desizing	300 - 1,100
Kiering	310 - 1,700
Scouring	2,300 - 5,100
Bleaching (range)	300 - 14,900
Mercerizing	27,900 - 36,950
Dyeing:	
Aniline black	15,000 - 23,000
Basic	18,000 - 36,000
Developed colors	8,900 - 25,000
Direct	1,700 - 6,400
Naphthol	2,300 - 16,800
Sulfur	2,900 - 25,600
Vats	1,000 - 20,000

[1] Cloth-weaving-mill waste (composite of all waste connected with each process).

TABLE 6-3
WATER USAGE OF MANMADE WET FIBER PROCESSES

Process	Fiber	Volume in gal/1,000 lb product
Scour	Nylon	6,000 - 8,000
	Acrylic/modacrylic	6,000 - 8,000
	Polyester	3,000 - 5,000
Scour and dye	Rayon	2,000 - 4,000
	Acetate	4,000 - 6,000
Dye	Nylon	2,000 - 4,000
	Acrylic/modacrylic	2,000 - 4,000
	Polyester	2,000 - 4,000
Salt bath	Rayon	500 - 1,500
Final scour	Acrylic/modacrylic	8,000 - 10,000
	Polyester	2,000 - 4,000
Special finishing	Rayon	500 - 1,500
	Acetate	3,000 - 5,000
	Nylon	4,000 - 6,000
	Acrylic/modacrylic	5,000 - 7,000
	Polyester	1,000 - 3,000

Source: John J. Porter et al., "State of the Art of Textile-Waste Treatment." EPA Pub. No. 12090 ECS, Clemson University Clemson, S.C., 1971 (1).

6.1.2 Flow Measurement

It is difficult from available information to account for high or low water usages in both small and large plants. Some studies have been performed which have estimated the manner in which water is employed in textile work (Tables 6-1, 6-2, and 6-3) (2), (3). In general there is little to be gained in discussing processes where the use of water is small, or the processes not of widespread application, in the trade. It also must be noted that measuring the quantity of water used in a machine for a certain process is not always simple with so many types of machines in use, and with great variations in size. Even with a number of machines of the same type it may not be feasible to employ the same method owing to inaccessibility of pipes or variations in piping sizes or types of joints.

The obvious method of measuring with a meter the amount of water going to or from a machine is an easy way of determining the volumes used by taking readings at each step of the process. Indicated in Figure 6-1 is a meter which features flexibility of installation and a "leak detector." But there are a number of difficulties that may prevent use of meters, such as high costs, temperature, corrosive liquids, and accessibility.

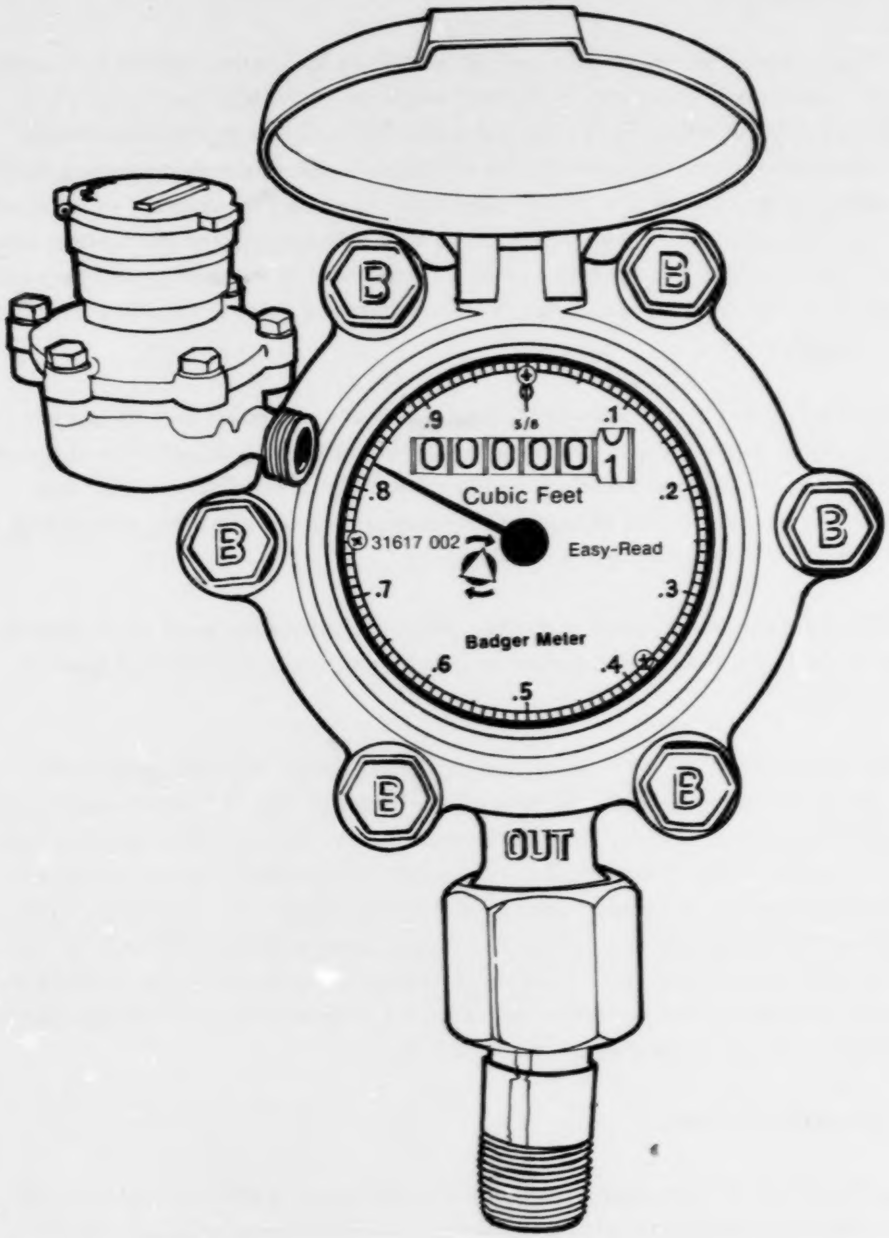
Rotometer devices are commonly found on textile ranges. Unfortunately many are neglected. Total water to a plant may be known, but rates of flow to continuous processes are generally not closely controlled.

Two excellent reference sources which simply and practically discuss flow measuring options available are the *Handbook for Monitoring Industrial Wastewater* (EPA), and information provided at the EPA Technology Transfer Seminar, Boston, January 1975 (4), (5). These methods include details from the simple "bucket timing" procedure, pump timing, a portable weir discharge system (can be used in trenches), to the more difficult salt injection procedure. Other procedures may include calculating the volume of a simple machine from its dimensions. Another method is collecting outflow from a machine by means of a portable pump with a suction leg, and pumping through a meter or vessel where it can be measured. Figure 6-2 shows a hook and gauge portable weir system used by one consultant (5).

6.1.3 Information to Collect

Recording loading, depth of water used, spray rates (bucket and stop watch), number of fills, etc., will help enable working figures to be obtained for process water usage per pound of material processed. Measurements should be taken for at least 3 months, but, ideally, for 12 months to give the most reliable information (3).

In individual reports, it is necessary to obtain figures related to specific fiber type, speed, and weight showing water usage for that particular production period. This is because when a low production rate occurs it is often found that low loading of many machines occur, rather than


.9
5/8
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000001
Cubic Feet
.8
.2
31617 002
Easy-Read
.7
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Badger Meter
.6
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B
OUT

FIGURE 6-1

FLEXIBLE FLOW MEASUREMENT DEVICE WITH LEAK DETECTOR

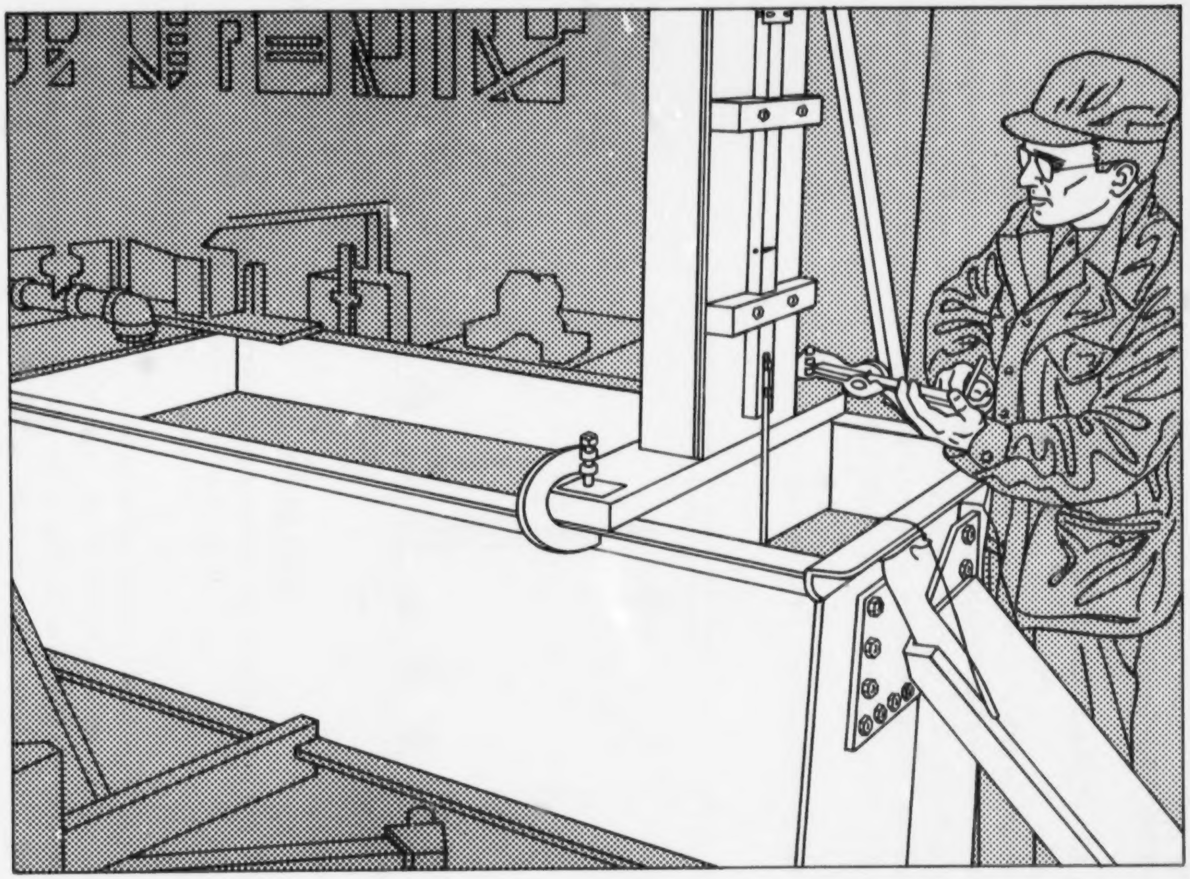


FIGURE 6-2

WEIR BOX WITH VEE-NOTCH WEIR AND HOOK GAUGE
(A. J. STEFFEN, BOSTON EPA TECHNOLOGY TRANSFER SEMINAR, 1975)

the correct loading. This, of course, gives high values for water usages per pound of material. Therefore, it is felt that long term figures will give a better indication of water usage because of the great variations in production rates that can occur over a period of time. It is also important to have information related to vessel temperatures recorded.

6.1.4 What Are Others Doing

6.1.4.1 CDTRA Study Results

It is useful to have an idea of how much water is used by others in various textile processes. The following sequence of tables is admittedly limited in scope, but attempts to provide insight into how much water has been used by process, equipment type, and dyestuff (3). It should be mentioned that little has been studied industry-wide in the U.S., and the generalities which are made are based on limited results; therefore, they should be tempered with engineering judgement.

In Figure 6-3 scouring water usages by equipment are compared.

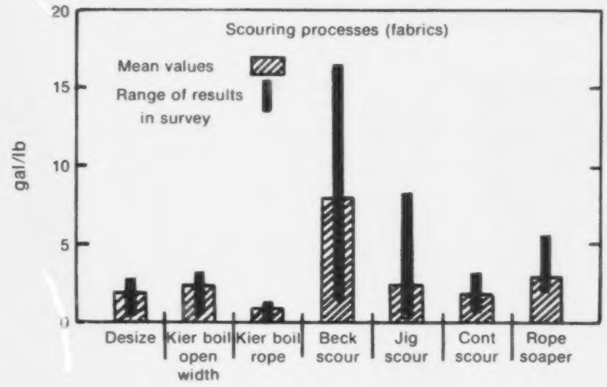


FIGURE 6-3
WATER USAGE IN SCOURING PROCESSES
(Fabrics)

It should be noted that kier boiling of cotton allows batch treatment of up to 2 tons or more at a time. Man-made fibers are less amenable to bulk handling and loads of 500 lbs. are uncommon. Scouring in kiers gives very low water usage in the process itself; subsequent washing is discussed later. Desizing water usage varies due to the variety of methods employed for desizing. A range of usage is included in the table from 0.03 to 0.16 gal/lb., with usage in washing from 0.4 to 2.9 gal/lb. A usage rate for several man-made fiber fabrics used from 8.3 to 17.4 gal/lb. in desizing. Scouring in a beck is usually followed by bleaching or dyeing. Beck scouring alone required water usage from 1.2 to 3.6 gal/lb. The table reflects the overall total. All the values for washing above 5 gal/lb. were produced by running rinses. Values for jigs depended on the fabric batch size. Values of 0.06 to 0.5 gal/lb. were obtained for scouring. Washing figures ranged from 0.2 to 0.3 gal/lb. Overall jig figures are indicated in Figure 6-3.

Comparing continuous scouring figures is difficult because of range configurations and intermediate treatments. Therefore overall scour and wash figures are given. The point to be made here is that many machines run at the same cloth speed and water input. Therefore, lightweight fabrics show high water usage values.

Focusing on strictly washing, Figure 6-4 shows considerable difference in water usage between firms.

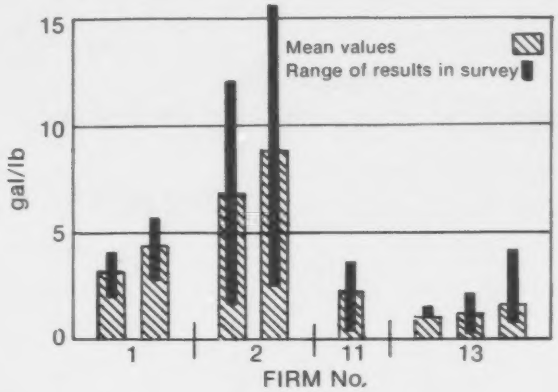


FIGURE 6-4

WATER USAGES: ROPE WASHING OF COTTON FABRICS, DIFFERENCES BETWEEN FIRMS

The major differences between water usage seen in Figure 6-4 appears in the manner in which machines are loaded as shown in Figure 6-5.

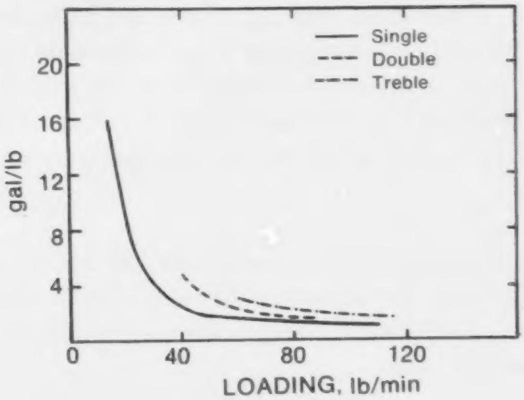


FIGURE 6-5

ROPE WASHING OF COTTON FABRICS: EFFECT OF MACHINE LOADING

Although it may not be feasible to alter cloth speed because of mechanical difficulties, judicious reduction in water feed rate for light fabrics may give rise to substantial economies. However, it is true that this can be detrimental for certain heavier fabrics. In general, usage figures were below 4 gal/lb. The same should hold true for open-width fabrics. A good figure to focus on, derived from this study, is approximately 0.7 gal/lb. goods.

Table 6-4 compares water usage for cotton fabric washing. Rope figures were higher than open width. However, in any specific case, it is a combination of fabric weight, temperatures, equipment type, speed, and water feed rate which primarily dictate water usage.

TABLE 6-4
WATER USAGE IN WASHING PROCESSES

Method	Water Usage — gal/lb	
	Average	Range
Rope	3.5	0.65 - 15.4
Open width	1.3	0.23 - 5.8
Jig	7.0	0.06 - 35.6
Winch	8.3	2.0 - 32.5
Beam	4.6	3.8 - 5.4*
Pit	3.4	0.93 - 8.0

*Without cooling water

In the jig, static washes showed the highest usage figure to be 3.3 gal/lb. Running washes produced figures from 0.06 to 35.6 gal/lb. In some cases longer rinses were used to remove loose color in reactive or azoic dyeings. In other cases running water was used to oxidize vat and sulfur dyes. Batch weights of from 2.4 to 100 pounds were also observed. To further indicate reasons for the wide discrepancies, cloth speeds were seen to vary from 53 to 140 yds/min among the jigs surveyed.

Becks are used to wash after scouring, bleaching, and dyeing. The water usage figures reflect the degree of residue removal difficulty. The figures are also somewhat cloudy because processes interspersed with washing may be included. A single wash was seen to run between 1 and 14 gal/lb. Table 6-4 shows the overall range.

Beam washing figures may double when cooling water is figured in. Efforts should be made to reclaim this cooling water.

6.1.4.2 Dyeing Process

Accurate data on dyeing are difficult to obtain. One reason is because of the variations in pretreatment and aftertreatment which can take place. Therefore, strict comparisons should not be attempted.

A general trend which occurs on the same equipment (jig or beck) is that particular dyes or certain fabrics can use far more water than when other dyes or fabrics are processed.

Figure 6-6 indicates the wide range of water used for fabric dyeing on various types of equipment.

In an attempt to focus more closely on the reasons for wide swings of water usage, water usage by dyestuff was examined for jig dyeing. Table 6-5 shows the water usage of various dyes using the jig.

Again it is seen that wide variations in water usage occur. However, when the effect of cloth weight is considered, trends become apparent as is shown in Figure 6-7.

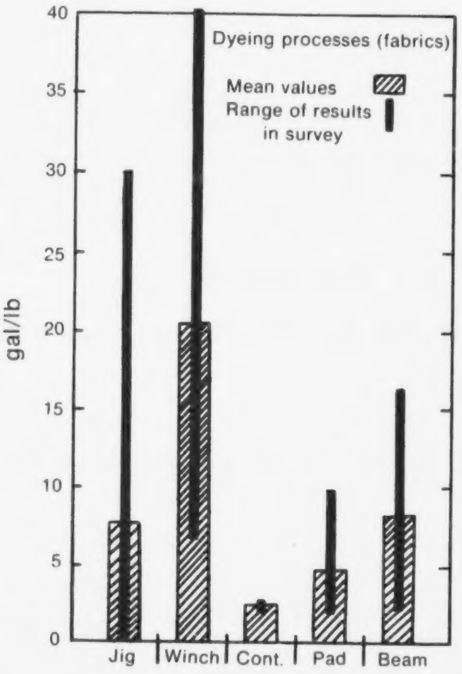


FIGURE 6-6

WATER USAGE FOR VARIOUS EQUIPMENT

TABLE 6-5
JIG DYEING WATER USAGES COMPARED

Type of Dyestuff	Water Usage gal/lb	
	Mean	Range
Direct	4.5	0.7 - 17.4
Azoic	15.8	-
Vat	6.4	2.7 - 12.6
Reactive	12.0	6.5 - 21.1
Sulphur	9.7	2.2 - 35.8

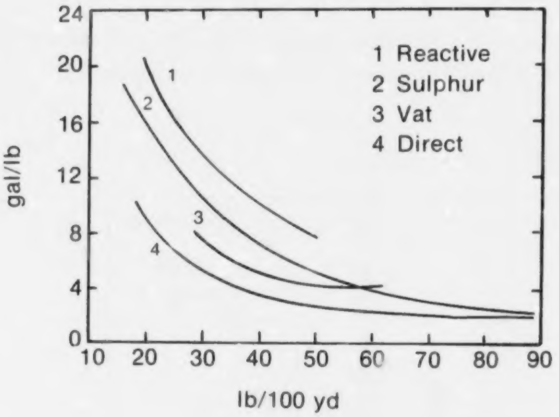


FIGURE 6-7

JIG DYEING — EFFECT OF CLOTH WEIGHT AND DYEING PROCESS

For a given size beck and a given dyestuff, the effect of batch size is seen to be marked.

Batch size – lb.	380	450	505	600	750
Water usage – gal/lb.	16	13.5	12	9.8	8.4

On the other hand, the effect of fabric weight was seen to be small, as was the effect of the type of dyeing. The following table shows that, if the batch size remains the same, water usage was seen to increase linearly with machine volume.

	Batch Size – 250 lb. Crimplene		
Machine volume (gal)	600	800	1000
Water Usage	12.2	15.8	20

Continuous dyeing data was scarce in the CDTRA study (3), but water usages appeared to be in the range of 2 to 3 gal/lb. (pad, develop, wash). Usage decreased with increase in speed (lb/min) as with other continuous processes.

Beam dyeing using disperse dyes ranged from 3 to 24 gal/lb. High water usages could be related to the amount of cooling water used.

Table 6-6 gives information comparing various average usages with equipment. Insufficient data increases the unreliability of the information, but trends are indicated.

TABLE 6-6
WATER USE COMPARISON

	Water Usage gal/lb				
	Vat	Direct	Disperse	Reactive	All dyes
Jig	5.7	4.0	–	9.7	7.7
Beck	–	10.4	12.5	21.4	20.3
Beam	–	–	11.0	–	11.0
Continuous	2.3	–	–	–	2.3

Package dyeing was studied at four plants using a variety of machines and sizes, a variety of fibers, and a variety of dyes (3). Water usage figures varied from 2 to 23 gal/lb. with the bulk of the figures in the 5 to 10 gal/lb. range. Focusing on machines loaded to the maximum enabled patterns to become clearer. Cotton yarn dyed with direct dyes, and polyester and nylon dyed with disperse dyes, used comparatively less water than reactives and vats, reflecting the complexity with dyeing procedure of these dyes. In direct dyeing, cotton running washes accounted for two-thirds of the water used. Whereas, in dyeing polyester yarn, running washes accounted for one-quarter of the total usage. Cooling water was 14 to 60% of the total. For the dispersed dyed polyester, overall consumptions ranged from 3.6 gal/lb. for the large units to 16 gal/lb. for the small units. Larger machines used proportionally less cooling water than smaller machines to account for some results.

Four plants were studied to determine water use in nylon hose dyeing in paddle machines. Water usage varied on the average from 9 to 24 gal/lb. (3). Measurements indicated that 15 to 55% of the water could be saved. Practical changes likely to affect water savings included the use of larger bags, fewer baths, heavier loads, and a comparison of running vs. static rinses.

Four plants were also studied to determine water usage for acrylic garment dyeing in paddle machines (3). Average water use for the plants varies from 10 to 23 gal/lb. Measurements indicated that 33 to 65% of the water used could be saved. Practical changes likely to affect water savings included achieving greater consistency, reduction in time and volume for running rinses, heavier loads, and also where feasible, machine conversion to closed coil cooling and heating systems.

Again, four plants were studied to determine water usage in paddle machines for wool garment dyeing (3). Average water usages ranged from 26 to 46 gal/lb. Practical changes likely to affect water savings included a reduction in time and volume of running rinses, more careful loading of machines, and greater consistency. The measurements suggested that 18 to 48% of the water used could be saved.

Water used in blanket washing for roller printing in three plants varied from 0.1 to 5.6 gal/yd.

Three plants reported water usage for print screen washing. About 15 gal/screen or 0.3 to 0.5 gal/yd printed fabric was used (3).

6.1.4.3 J. P. Stevens

Samuel Griggs of J.P. Stevens made the following general observations for water conservation efforts (4):

1. Turn off water to equipment that is not being used. Use of automatic shut-offs on hoses, etc.

2. Supply only the needed amount of water to a machine. (Don't use 30 or 40 gallons when 20 gallons will accomplish the same job.)

3. Modulate water use depending upon throughput of material. Use less water for narrower width fabric than for wider fabric.

4. Reuse non-chemical treated cooling water. Reclaim by running through a cooling tower or reuse in processes not requiring tap water quality.

5. Chemically treat waters for reuse. Print waste water can be clarified and returned to wash the blankets and screens of the print machine.

6. Steam condensate return.

Four Stevens plants in which the above methods were utilized are described briefly on the next page:

Plant 1

A plant with 13 300-pound kiers on stream with no water recovery was using approximately 700,000 GPD. Water supply was limited by pressure drop, etc.

Added 5 more 1000-pound kiers and activated a recovery system into a new hot water system under pressure. Also restricted water usages by placing flow reducers into large lines. Current wastewater is approximately 400,000 GPD.

Plant 2

Where 30 to 35 gallons of water was being used per pound of fabric dyed, conservation reduced the use to 18 gallons per pound of fabric dyed. This was accomplished by examining the process and restricting the water use.

Plant 3

Reduction of approximately 800,000 GPD going to waste treatment by the addition of a cooling tower on non-chemical treated cooling waters.

Plant 4

Savings of 288,000 GPD by adding a cooling tower to reclaim air compressor cooling water. Savings of approximately $18,000 per year resulted.

6.1.4.4 American Thread

Fred Eslick, American Thread, reported in 1975 on the results of his dyehouse Wastewater Management program at two plants (6).

Plant 1 – 18% reduction in water usage per pound of yarn dyed and finished.

Plant 2 – Dyehouse effluent and water used per pound of yarn was reduced 15%.

6.1.4.5 Corlin Processing, Landis S.C.

Lane Drye, President, says his company cut yarn dyeing water requirements from 75 to 35 gal/lb. by discovering and eliminating waste areas (7). This good water management was accomplished in 1971 and both cut costs and reduced the load on the municipal treatment plant.

6.1.4.6 Springs Mills

J.D. Lesslie, Director, Utilities Service, stated that in April of 1974, Grace Finishing Plant reduced its water usage in ony year by 25% (8). This is more dramatic when observing that the reduction was from 16 million gal/day to 12 million gal/day.

These previous case histories were offered as various examples of what can be accomplished. The potential at this time is obviously considerable, even without extensive study or elaborate equipment redesign.

The next area of discussion considers what specific steps may be taken, and what equipment manufacturers are doing, to help the situation for the future. It may also be taken to indicate where vendors might be actively encouraged to intensify efforts for the future.

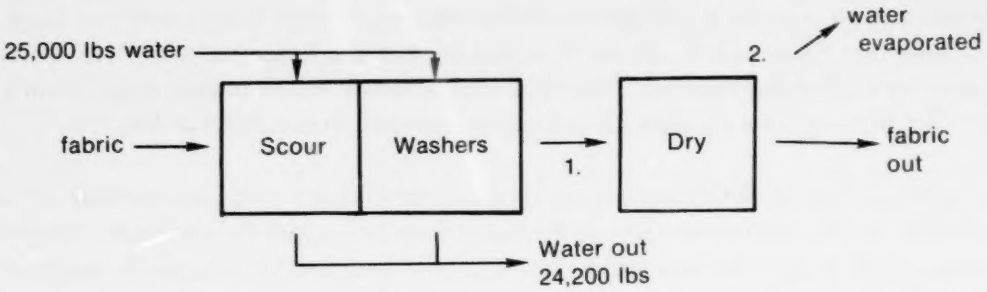
6.1.5 Recommended Approach

Perhaps the most important approach for the textile engineer of the future is to devise material balances for each major production area. An example is given in Figure 6-8 of a cotton scouring material balance for a particular style. A complete and concise idea of chemical formulation, estimated waste output, moisture lost, water used per pound of product and a waste parameter analytical checklist are readily apparent at a glance. Any changes can be gauged against this material balance and cost/benefit decisions can be made. Other material balances including comparing starch sizing with PVA sizing, a vat dyeing material balance indicating the various alternatives available for oxidizing the dyestuff, etc., should also be drawn up to stimulate thought. Note particularly where BOD sources occur.

A more detailed material balance, perhaps best conducted by a consultant, is shown in Chapter 5, Figure 5-7. Here the fabric and wash box water alkalinity are measured to determine whether excessive washing might allow elimination of a wash box. Another reason for such a study would be to determine whether counterflow washing at reduced rates and temperature is feasible (4). Chapter 5, Figure 5-7, it should be said, is a somewhat simplified worksheet.

Chapter 5, Figure 5-6 shows, in simplified form, how a dye range material balance might be approached (4). Changes in formulations, flow rates, etc., can be gauged against this basic evaluation for cost benefit purposes.

These are but some of the approaches which can be used, not only to reduce water volume, but also to provide cost saving benefits in general.


25,000 lbs water
fabric
Scour
Washers
1.
Dry
2.
water evaporated
fabric out
Water out 24,200 lbs

Chemical Throughput	Input (lbs)	Output (lbs)	lb BOD per 100 lbs output (%)	BOD output (lbs)
NaOH	46	46	0	0
Detergent	1.3	1.3	50	0.65
Tri-Sodium Phosphate	1.5	1.5	0	0
Chelate	0.4	0.4	50	0.2
Tri-Ethanol Amine	0.7	0.7	50	0.4
Cotton Wax	30	30	50	15.0
Suspended Solids (SS)	5	5	2	0.1
				16.4 total

Flow rate = 70 GPM

Production rate = 80 yds/min

1. percent moisture on fabric = 80% pick-up
2. avg. 80% pick-up = 800 lb water lost (evaporated)

water used 25,000 lbs ÷ 8.33 lb/gal = 3000 gal
wastewater out 24,200 lbs

water/lb fabric = $\frac{3000 \text{ gal}}{1000 \text{ lbs}}$ = 3 gal/lb

Analytical Checks

BOD	16.4 lb
Total SS	5 lb
Total Dissolved Solids	49.9 lb
pH	12.5
Oil and Grease	30 lb
Toxic Materials and Other	1.04 lb (as phosphate)

FIGURE 6-8

SCOURING RANGE MATERIAL BALANCE

Scour — 100% cotton woven, 3.5 yds/lb, 80 x 80 construction (light weight) Lot X, Total Production Basis — 1000 lbs.

Elaboration on a specific study may be helpful here (9). The scenario includes a single stage bleach range processing 65/35 polyester/cotton knit goods in rope form, a saturator, J-box with wet-heel, and six box-washers with acetic acid scour form the equipment units. Specifications require 30-40 GPM flow between 170-190° F. Fabric caustic concentrations ranged from 0.21 to 0.33%. Washed fabric concentration of caustic averaged about 0.025% at 40 GPM.

Reducing the flow to 15 GPM only increased the washed fabric average concentration of caustic to 0.033%. Measurements were taken at the fourth wash box before the acid scour. Temperature increase of the wash water from 145 to 205° F showed only a 0.01% decrease in caustic residual. By lowering the flow rate to a conservative 20-25 GPM and lowering the water temperature to 140 to 160° F an energy savings of approximately 50% is possible, as shown in Figure 6-9.

After considerable experience gained on washing caustic scoured cotton yarn packages in the laboratory, mill trials were conducted (9). Gaston County equipment holding 100 packages of 1.25 lbs/ package was used. The packages were impregnated with approximately 1.2-2% caustic on the weight of the yarn. The trial indicated that yarn washed with a 3-minute hot running rinse and 3-minute cold rinse at 2 gal/min/lb. was essentially equivalent in residual caustic content to a 10-minute hot running rinse and a 10-minute cold rinse, the latter being the routine plant procedure.

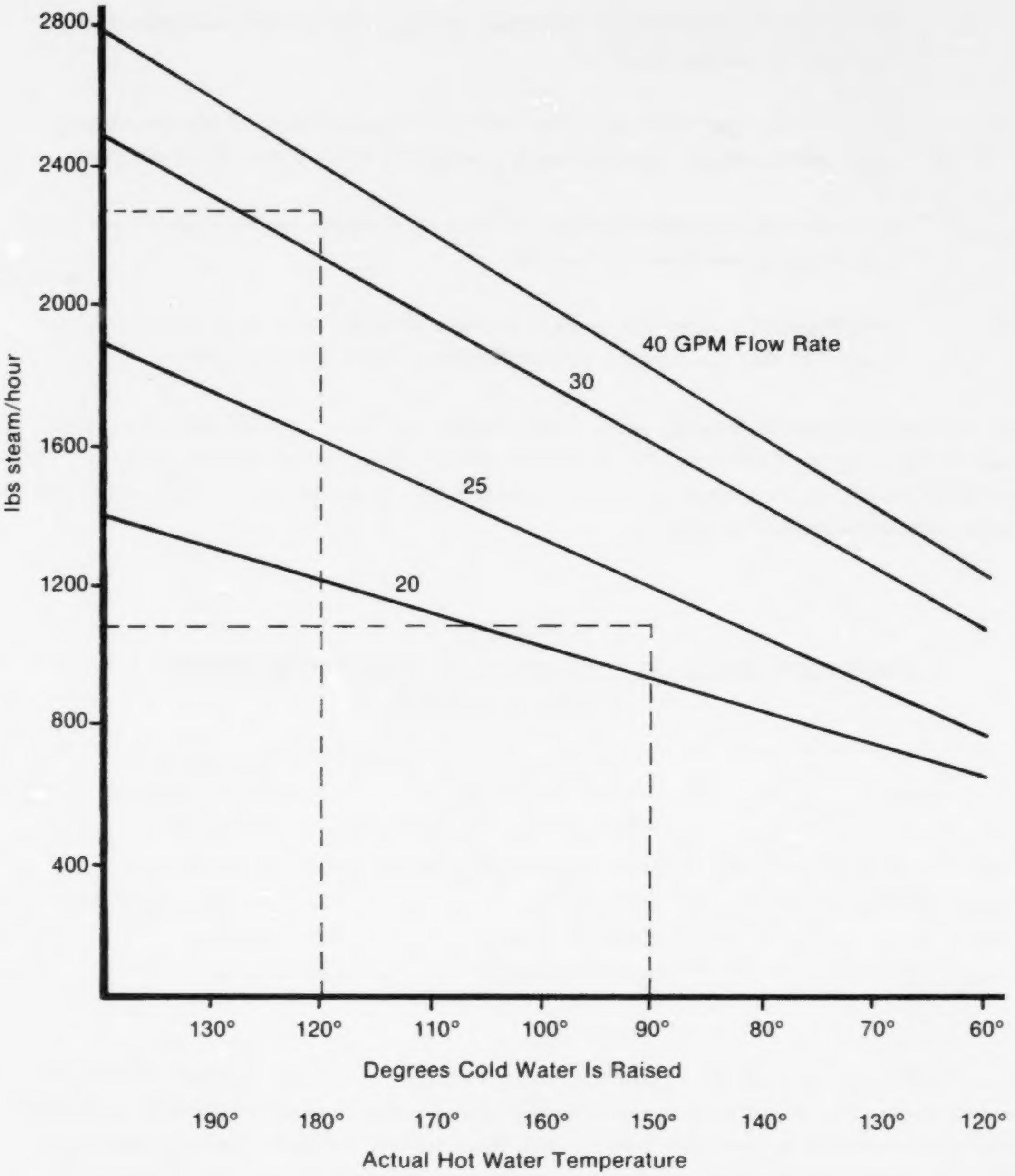


FIGURE 6-9

ENERGY CONSERVATION ON THE CONTINUOUS RANGE

Other conclusions included:

1. Due to caustic's high affinity for cotton, running rinses, rather than recirculating rinses, were recommended.

2. Flow of 2 to 3 gal/lb/min at 140 to 150° F for approximately 3 minutes running rinse (inside-out) are suggested starting points for 40's 2-ply to 90's 2-ply yarn.

3. It is indicated that approximately 0.05% residual caustic on the weight of the yarn is generally a good degree of removal.

4. Significant differences in efficiency of removal were seen to occur between very coarse and fine yarn counts, yarn twist, and packages winding densities.

Other studies compared high energy open-width washers with the conventional box washer in terms of caustic removal efficiency (9). It was found that the important variables involved ranked differently for the various washers. The variables are ranked in order of importance for caustic removal by washer in Table 6-7.

TABLE 6-7

PREDOMINANCE OF VARIABLES IN CAUSTIC REMOVAL BY THREE WASHERS

Box	High energy cascade principle Gaston County Alternator	High energy vibration principle Daiwa Vibro
Fabric caustic concentration	Fabric caustic concentration	Water temperature
Water temperature	Fabric speed	Fabric caustic concentration
Fabric speed	Liquor/fabric ratio	Rotor speed
Liquor/fabric ratio	Water temperature	Fabric speed

Temperature was seen to be the second most important aspect of caustic removal efficiency in the box washer. The high energy imparted by the Cascade concept displaces the dominant rank of temperature in the scale of importance to last. Restricted by the limitations of temperature effects in caustic removal, the box cannot compete in potential caustic removal effectiveness with the Cascade. Studies with the vibrating washer indicate that not all the principles of high energy washers will provide greater efficiencies at economical prices (9). For example, in this study it was observed that the vibrator was similar to the box washer in caustic removal efficiency without the rotor operating. In order to reach the Cascade efficiency, uneconomically high rotor speed power was required.

In a mill trial, the Cascade equipment was compared to a vibrating washer after a recuperator in a chainless mercerizing range using 65/35 polyester/cotton fabric (9). The alternator was found to be substantially more efficient.

Tables 6-1 and 6-2 serve especially to indicate that the washing of wool and the washing of cotton after dyeing are two areas suggesting great potential for improved water economy (10).

Washing operations are obviously then high priority areas for water economy improvements. It is not difficult to envision washing machines that can achieve considerable savings in water usage. This is particularly true in view of the fact that water economy has not been a high priority design consideration in the past.

The need for less water usage and increased efficiency of washing is accompanied by the need for other important design considerations. These considerations include:

- no excessive tension or abrasion
- reasonable cost
- easy thread up
- capability of accommodating a range of fabric weights, width and types
- durability to high speed operation
- low energy consumption

The Tensitrol washer for rope goods can perhaps be called a forerunner of sophisticated development in washer design. The test results shown in Table 6-8 for the Tensitrol are good examples of the information which should be demanded by mill personnel (11).

TABLE 6-8
FLEXIBILITY INDICATED BY TENSITROL WASHER

	Test A	Test B	Test C
MATERIAL	Caustic treated dress goods, 4.73 yds./lb., singed, mercerized but not scoured	Caustic treated poplin 3.04 yds./lb., mercerized but not scoured	Acid treated fabric H_2SO_4 singed, mercerized and scoured with excess of acid
WATER USED	40 gal./min.	47 gal./min.	48 gal./min.
STEAM USED (lbs. of water evaporated/hr.)	1050	1120	1120
SPEED (yds./min.)	208	215	215
WATER TEMPERATURE	160°F	160°F	160°F
WASH RESULTS Before wash After wash	 0.193% 0.015%	 1.661% 0.165%	 4.36% 0.21%

The information provided in Table 6-8 suggests versatility and therein makes available a concrete basis for reliable comparisons with other machines.

An open-width washer manufacturer attempts in Figure 6-10 to illustrate the influence of different design parameters in their washer on improved washing (12).

It is reasonable to encourage vendors to continue to improve their advertising by providing information on the effects of new design additions as indicated by the literature represented in Table 6-8 and Figure 6-10.

Table 6-9 is provided to indicate some of the varieties of new equipment types currently on the market and some of their important differences.

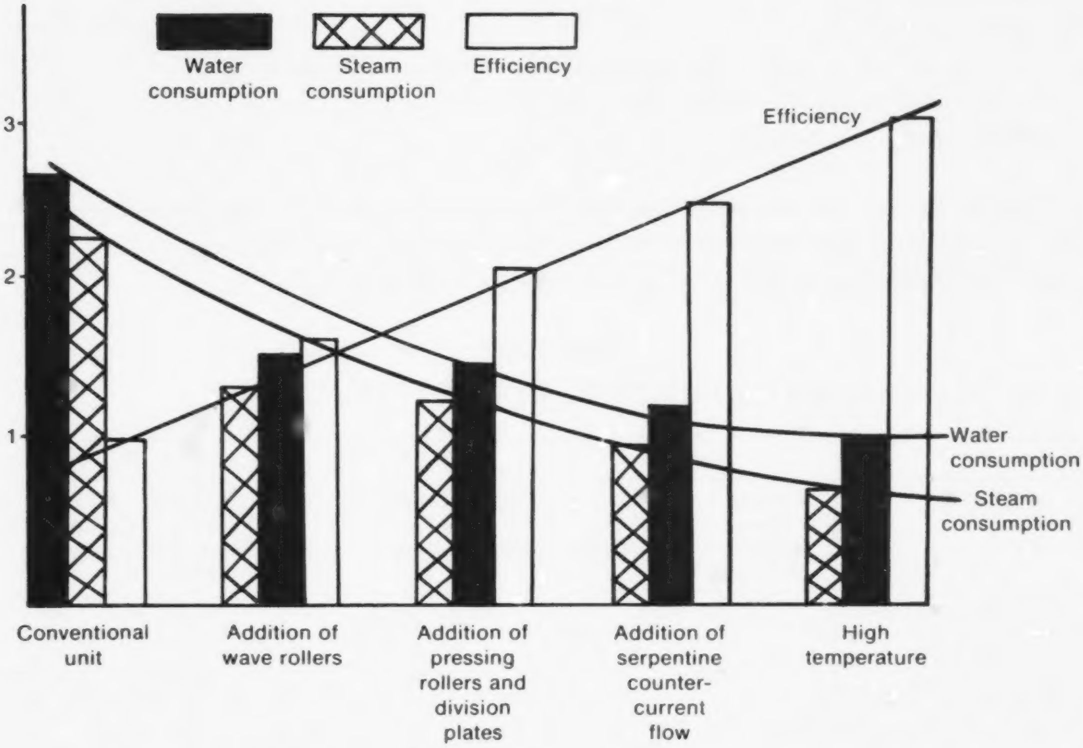


FIGURE 6-10

INFLUENCE OF DESIGN PARAMETERS ON IMPROVED WASHING

TABLE 6-9

SOME NEWER WASHING MACHINES

Type	Manufacturer	Features Claimed
Open-width	Rodney Hunt	Enclosed, requires less steam, can contain vapors and toxic fumes
Open-width	Greenville Steel	Counterflow arrangement, double-lacing allows 6 boxes to do work of 10 single laced boxes
Open-width	Farmer Norton	Suction washing
Open-width	Prelaval, Jawetex	For printed goods, special jet spray nozzles, woven or knits, 1:10 liquor-to-fabric ratio, 22 yds/min, 500 lbs/hr steam consumption
Open-width	Aqua-Blast, Amer. Laundry Mach.	Four high velocity jet manifolds, 20 gal/min with 55 yds/min, knits and woven, printed goods
Open-width	Lite-o-matic Omez	Water sucked through perforated drums, tensionless for knits and prints, sprays both surfaces
Open-width	100 plus unit, Kleinwefers, B-K	Fabric fed horizontally from bottom to top, water cascades from top to bottom, enclosed, under pressure (7 psig, 232°F), steam reduces fabric tension to promote flow through
Open-width	Greenville Steel	Horizontal carpet washer, 3 immersions-3 nips, agitators in each box
Open-width	Gaston County Alternator	Carpet, Cascade principle, adjustable gap setting
Open-width	Mather-Pratt Aquatex	Wave rollers, compartmentalization, high temperature, countercurrent flow
Open-width	American Artos	Horizontal fabric flow, no pressure, replaces three conventional washers

No matter whether water is forced through fabric by squeezing, suction, cascading, beaters, spraying, pulsing, or by other ways of creating turbulence, one is faced with a physical law which seems best overcome by time. It is in this respect that the means to improve the exchange between water and chemicals through fabric may be most limited.

For this reason the two most fundamental principles of washing which go into producing a good wash without excessive use of water warrant discussion. Generally, the effectiveness of a washing can be seen to increase directly with the volume of the wash water used, but it increases with the power of the number of washings used. Thus, fundamentally, four washings with 2.5 gal/lb. goods each can be a great deal more effective than a single 10 gal/lb. washing. Furthermore, it would be ideal to remove as much of the liquid as possible by squeezing and collecting before adding the next portion of wash water.

For example, Russell (ICI) argues in package dyeing operations that: The washing or soaping of dyed goods following the dyeing operation is an area where energy conservation is possible.

> The use of running rinses should be avoided, as they are great wasters of energy. Initially a running rinse should be used to remove the excess dye liquor. Thereafter, a drop and fill method is preferred to a running wash for two reasons. The governing rate in washing or soaping is the diffusion rate of the dye. This rate is best increased by increasing the temperature of the wash liquor. This will speed cleanup by increasing the diffusion rate of the dye. If hot water is pumped through the goods and allowed to go to drain, vast amounts of water and energy are wasted. This excess water also increases the cost of effluent treatment which is generally based on treated volume. Two fills and drops heated to 200° F will often accomplish as much as an hour of running wash at 160° F and will consume much less energy (13).

Eslick suggests that a careful look should be given to dye machinery that will be purchased in the future for replacement or expansion (6). Those machines with excessive or long runs of piping below the beck, kier or vat are less desirable than the same machines with short, compact piping. The liquor-to-pound of material ratio will be lower with the compactly piped unit, hence the water consumption will be lower. As a side benefit, the electrical cost to circulate the liquor will likely be lower.

Gelders (Lockwood Greene) reported that water usage can be reduced by one-third through utilization of dye cycle control (14). The controllers referred to are punch-card, programmed-type dye cycle controllers. Full automation also offers desirable side benefits of better product repeatability, low chemical utilization per pound of material, and lower maintenance cost to the dye machine itself. Eslick reported on two plants producing essentially the same goods, one was automated and computerized more fully than the other (6). The more automated plant showed significantly less water usage. More will be said on automation in subsection 6.5.

Solvent processing offers considerable potential for water conservation. This topic is treated under Process Changes, subsection 6.5.

There are trends which indicate a new generation of rapid package dyeing machines using short liquor ratios may be developing. Such equipment is said to offer rapid dyeing, reduced dye cycle time, and have reduced steam, energy and water usage (15). One manufacturer uses a tube arrangement with perforated tubes inside to hold packages. The outside tubes act as heat exchangers. This step eliminates the need for external heat exchangers and reduces the liquor ratio. The primary feature of this equipment is the pulsation principle which directs flow through only a certain number of packages while the remaining packages are shut off from liquor circulation for short intervals. If such equipment gains wide commercial acceptance the package dyer can be expected to use considerably less water.

There is a possibility where some package dyers may improve on water usage utilizing existing equipment. Those dyers who are using relatively non-compressible fibers might consider switching from rigid dye tubes to dye springs. Consider that the water and steam used to dye an overload is the same as a normal load. The results might be viewed as a 30% increase in production capacity for the same amount of fuel. Figure 6-11 indicates the compression obtainable using dye springs (16).

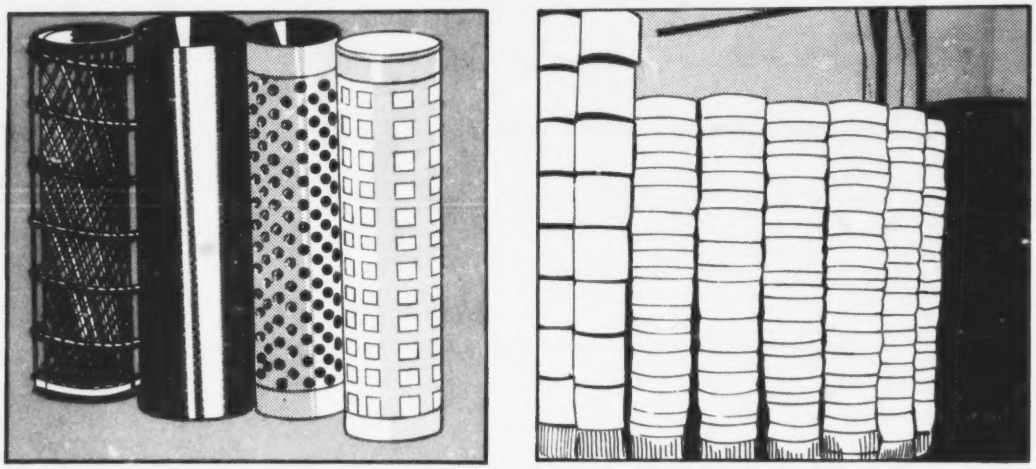


FIGURE 6-11
COMPRESSION OF LOAD USING DYE SPRINGS SEEN ON LEFT

For example, a package dyehouse dyeing 150,000 pounds of yarn in 120 hours uses 7,143 gallons of fuel oil to produce one million pounds of stream at 125 psig (0.0476 gallons of fuel oil per pound of yarn). Using dye springs and a 50% kier overload in lieu of any rigid tube method of dyeing reduces the fuel requirement to 0.0317 gallons of fuel oil per pound of yarn – for a possible savings of over 30%. For a 100,000-pound-per-week dyehouse, the savings are approximately 1,600 gallons of fuel oil per week, which is the equivalent of enough raw crude saved to produce 12,000 pounds of polyester.

6.1.6 Waste Volume Reduction Checklist

This section emphasizes the advantage of keeping waste volume as low as possible in order to get greater treatment efficiency on a "per pound of product" basis. Points touched upon included:

- Improved washer designs.
- Overflow vs. recirculating rinses in package dyeing.
- "Tailored rinses" – to fit the particular shade, style or severity of treatment.

- More careful control and testing to ensure that "over-rinsing" of fabric does not take place.
- Closed steam heating coils in dye becks, etc., rather than open steam, to allow return of condensate.
- Use of closed cooling coils rather than overflow cold water input.
- Return of suction slot liquors to wash-box make-up.
- Use of the counterflow principle, on continuous ranges.
- Vacuum extract on package dye machines.
- In-plant re-use of lightly contaminated rinse waters for other, more "concentrated" chemical processes.
- Return of water from water-cooled rolls (e.g., on coaters).
- Using automatic water cut-offs on ranges, for when range stops.
- Liquor ratio consideration in batch processes.
- Elimination of reworks by more careful control of processes and greater automation.
- Consider compressible springs in package dyeing for greater loads, less water and energy.
- Replace leaking pumps, heat exchangers, compressors, etc.
- Meter each range, keep shift or daily records on water use per unit of goods.
- Automatic cut-off on water hoses.
- Spring controlled faucets.
- In-line flow restrictions for certain machines.

6.2 Waste Strength Reduction

This subsection attempts to suggest some of those in-plant practices and equipment which might be considered in reducing plant waste strength. Two obvious purposes towards this end are to:

- Reduce treatment requirements and costs.
- Prevent troublesome or toxic chemicals from interfering with the waste system.

Perhaps, less obvious in this context, is that reducing waste can also reduce general wastefulness and lead to more efficient processing and cost savings.

The first step in such an undertaking is to have an idea of what materials and ingredients, such as, chemicals, dyes, oils, solvents, etc., are used in the plant and exactly how they are disposed of.

Before discussing more sophisticated approaches, the matter which should first be discussed is that of avoiding spillage. The production staff should periodically be made aware of the general wastefulness and potential harm to the treatment system that spills can contribute. Once the easy things are done, old habits reappear as the routine day-to-day continues. Monthly meetings are suggested which should partly concern themselves with how to motivate workers, keep their interest, and make them aware of the fact that top management is concerned. You can tell a man to watch that he doesn't spill, but the problem is that the tendency is to continue spilling. Today numerous companies create humorous, low-pressure, positive attitude posters. These posters can plant the seed of a positive attitude towards a man's job and the company he works for. They can also subtly remind workers to stay alert without confrontation or finger pointing.

A general waste reduction suggestion is to see that chemical mix amounts are carefully calculated, and periodically reviewed, to accommodate a specific fabric lot size, thereby preventing excessive dumps. Probably more overall care could also be taken to adjust process chemicals to more nearly correspond to the particular fabric weight being run. For example, a number of continuous bleach ranges have been observed running on formulations which are designed to take care of the most intractible fabric style being run. This means that there is "overkill," or chemical wastage on lighter, more easily treated fabrics (9). Thoughtful segregation of various styles into groups, with different formulations for each group, is suggested.

In a similar vein, the use of control equipment designed to feed in chemicals should be considered. Experience has indicated that poor results have occurred from low concentrations, and fabric damage has resulted from high concentrations (9). There is available proven equipment which can maintain bath concentrations of predetermined levels. This can reduce waste strength and save chemical costs for the mill. One piece of equipment on the market, Figure 6-12, has suggested potential application for all chemical concentrations which can be analyzed by

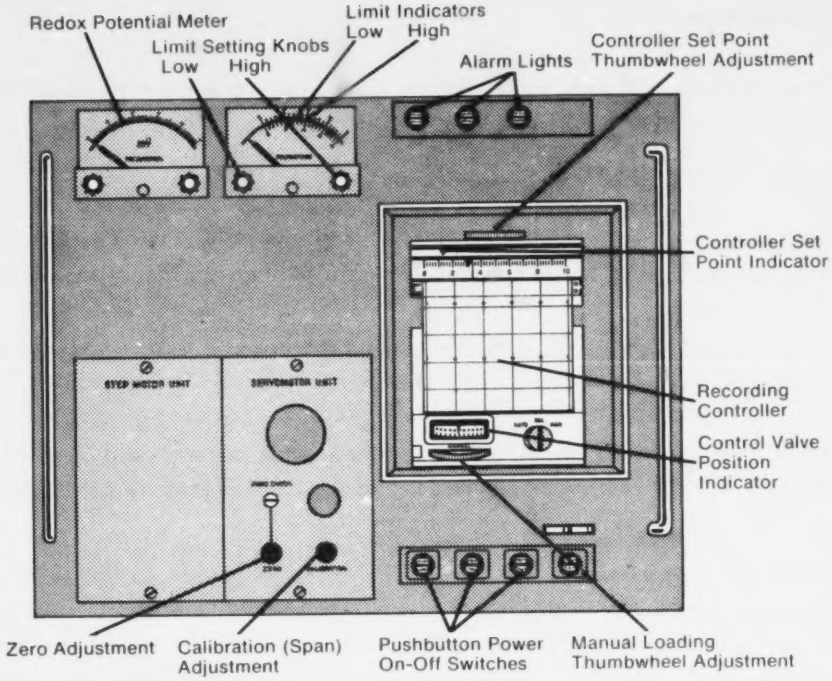

Redox Potential Meter
Limit Setting Knobs
Low
High
Limit Indicators
Low
High
Alarm Lights
Controller Set Point Thumbwheel Adjustment
Controller Set Point Indicator
Recording Controller
Control Valve Position Indicator
Zero Adjustment
Calibration (Span) Adjustment
Pushbutton Power On-Off Switches
Manual Loading Thumbwheel Adjustment

FIGURE 6-12

AUTOMATIC CONTROL OF CHEMICALS

redox titration, such as peroxide, caustic, silicate, sodium hydrosulfite bichromate, bromite and so on (17). Savings at Dan River, for example, have been claimed to be up to 30% using such equipment (18).

The following curves, Figure 6-13, indicate the difference between automatic control of peroxide and alkali over manual control. Such units would sell for approximately $23,000. Application examples for this equipment are shown in Figure 6-14.

In bleaching an automatic system can replace constant feed pumps which would otherwise pump caustic and peroxide into the saturators of the bleach range. In the manual mode, an operator usually withdraws a sample from a saturator and titrates to an indicated end-point, and thereby determines the chemical concentration. Then he either increases or decreases the pumping rate to compensate for any deviations from desired levels. After calibration and a short stabilization period in the morning, automatic controls constantly monitor bath concentrations and adjust control valves that meter in chemicals. For example, a manual system running 30% over a desired 1.0% caustic concentration for polyester/cotton blends can run 6,000 yards of goods by, if the titration period is 30 minutes and the speed 200 yds/min. This means wasted chemical, possible dye problems ahead, and more alkali for the waste treatment system to handle.

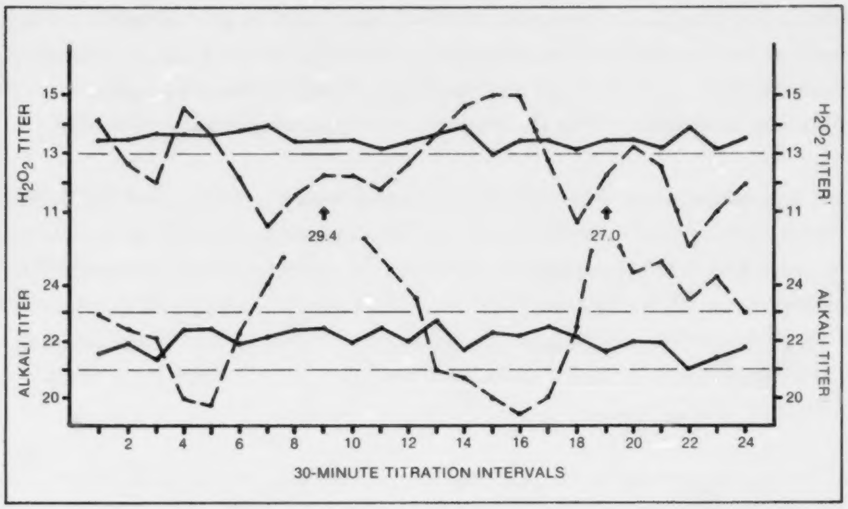


FIGURE 6-13

COMPARES AUTOMATIC CHEMICAL CONTROL WITH MANUAL CONTROL. DOTTED LINES ARE MANUAL CONTROL.

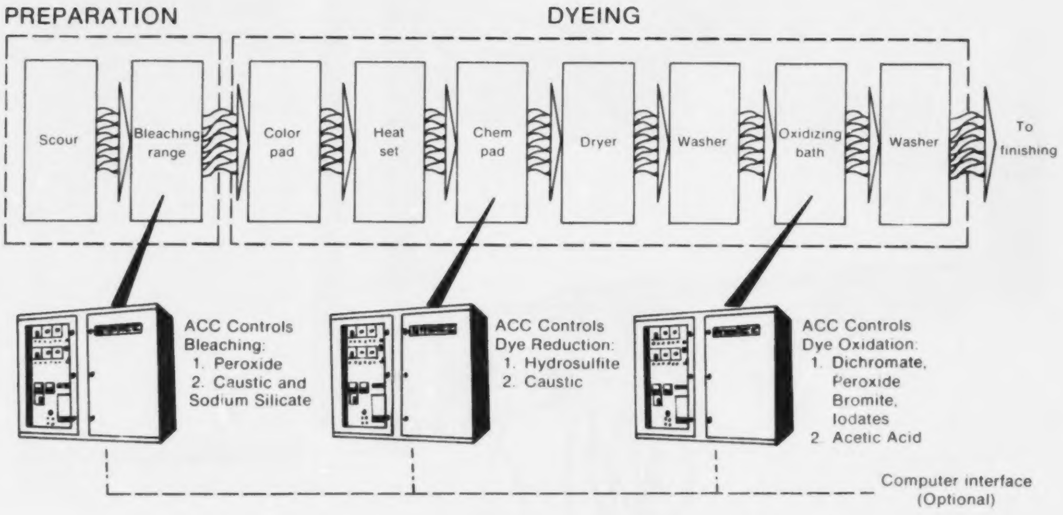

PREPARATION
DYEING
Scour
Bleaching range
Color pad
Heat set
Chem pad
Dryer
Washer
Oxidizing bath
Washer
To finishing
ACC Controls
Bleaching:
1. Peroxide
2. Caustic and Sodium Silicate
ACC Controls
Dye Reduction:
1. Hydrosulfite
2. Caustic
ACC Controls
Dye Oxidation:
1. Dichromate, Peroxide Bromite, Iodates
2. Acetic Acid
Computer interface (Optional)

FIGURE 6-14

POSSIBLE POINTS OF APPLICATION FOR AUTOMATIC CHEMICAL CONTROL

The best point of application of automatic control equipment in general would be in preparation. It is here where the potential for error and problems is greatest, i.e., it is difficult to see when an error has been made. Perhaps the operation of such delicate equipment, i.e., the set-up and calibration, should be left to the research or engineering departments (18).

A recent wet process monitor, Figure 6-15, for carpets is said to have saved $120,000/year in carpet latex overages. A fabric model would cost approximately $8,000, while a carpet model should be expected to cost approximately $15,000. Wet process monitors designed to prevent chemical overages in open-width processing suggest themselves, also. Such equipment is applied at the pad nip to determine wet pick-up. Proper use and stable humidity are two critical factors in successful usage. In suitable applications such equipment can aid uniform wet process application, Figure 6-16.

A great degree of waste strength reduction can be obtained by removing fibers and lint. Fibers and lint can contribute "latent" or hidden BOD, add to COD, and cause SS carryovers from

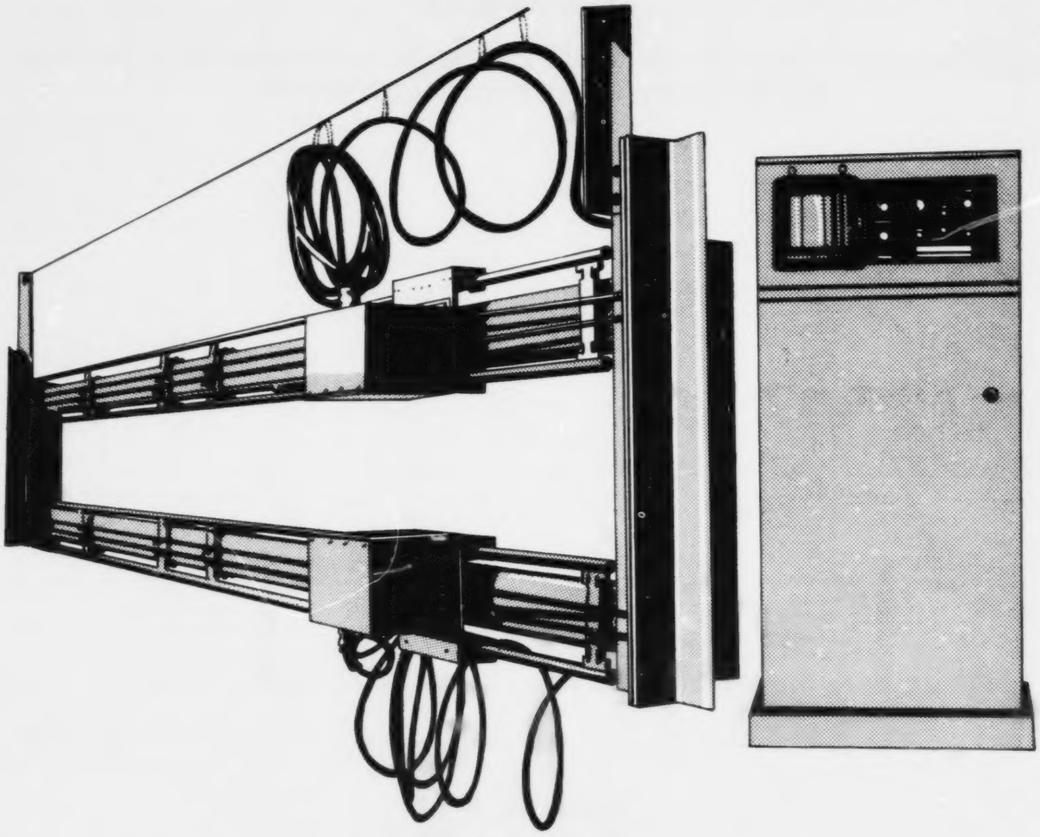


FIGURE 6-15

WET PROCESS MONITOR FOR CARPETS HELPS PREVENT LATEX OVERAGES

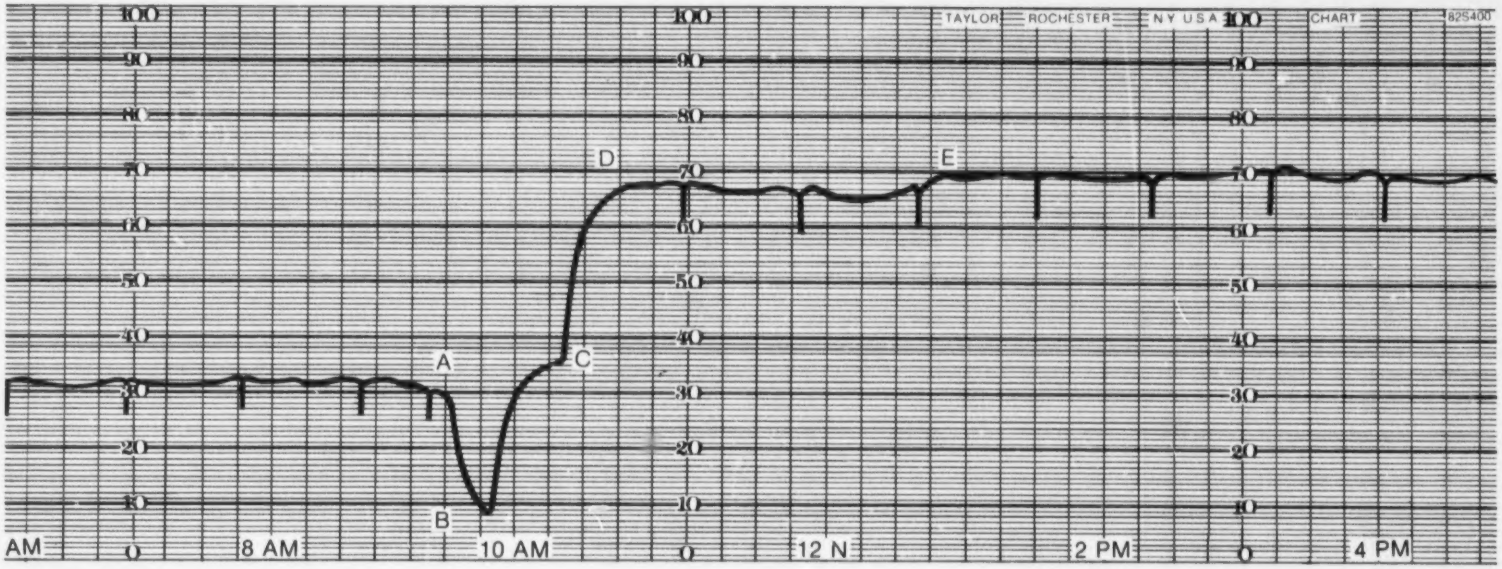


FIGURE 6-16

This chart illustrates the measuring capability of a wet processing monitor. One style of cloth finishes its run at a point A — the monitor is turned off and leader cloth continues into the dye range. At this point, the range is stopped, cleaned and prepared for the next run.

The range is started and the monitor begins monitoring at B. Chart areas B to C represent the leader cloth. From C to D style 17399 begins to pick up the dye (time — 33 seconds). From D to E the chart areas between the downward blips indicate side-to-side cloth shading — at E with the guidance of the monitor, adjustment of pad roll pressures has been made and the dye range is set within 2 minutes for its run (17).

clarifiers. Lint has also been known to clog flow meters, pipes, pumps and tangle aerators. Fine screens applied in drainage ditches is one way of collecting undesirable fibers.

If an analysis indicates that a plant has high concentrations of BOD, COD, heavy metals, oil/grease, etc., compared to its ATMI Category average, then it is suggested that a shift of chemicals may reduce the concentrations in the wastewater. Eslick suggests that much of the clean-up work must be done by the plant dyer and dye chemist (6). Sodium chloride, sodium sulfate and sodium hydrosulfite are cheap, commonly used chemicals in the dyehouse. Since they are cheap, it is not unusual to see them over used. These chemicals cannot be removed by biological methods and management should therefore insist on minimal use of these chemicals. Furthermore, sodium hydrosulfite has been seen to contain residual zinc catalyst.

Many solvents contain phenols and many lubricating oils and greases contains substantial amounts of zinc and lithium. Some departments have been observed simply to pour these items down the plant drains after use.

Eslick goes on to suggest that production planning done strictly on the basis of customer service may require consideration in the near future. For example, short dye cycling for dye days can lead to inordinately high daily flows and pollutant concentrations. It would be better for the dyer and dye chemist to inspect orders on a weekly basis in an effort to plan production and avoid shock loading of the treatment system and still provide good customer service.

Carriers are known to contribute heavily to waste strength. Table 6-10 indicates the BOD_5 of various polyester dye carriers. Dye formulations for atmospheric dyeing will be using the greatest amount of carrier annually. Many of these carriers today will likely contain phenols also. Higher temperature dye machines can help reduce the use of carriers and should be considered for use when replacement is necessary. Table 6-11 compares the discharge characteristics when various carriers are used. Table 6-12 shows the priority potential for waste strength reduction in vat/disperse dyeing is greatest for carrier reduction.

TABLE 6-10
BOD LOADINGS OF POLYESTER DYE CARRIERS

Carrier	BOD	
	ppm	lb/1,000 lb cloth
Orthophenylphenol (most used)	6,000	180
Benzoic acid	27,000	810
Salicylic acid	24,000	720
Phenylmethyl carbinol	19,000	570
Monochlorobenzene (toxic)	480	14

Source: John J. Porter et al., *State of the Art of Textile-Waste Treatment*, EPA Pub. No. 12090 ECS. Clemson University, Clemson, S.C., 1971 (1).

TABLE 6-11
SCOURED AND DYED POLYESTER

Chemical throughputs	Input, pounds	Output, pounds	Unit BOD, lb/100 lb output	BOD output, pounds
Item:				
Nonionic surfactant	30-35	30-35	3	0.1
Anionic surfactant	10	10	80	8
Carrier-*o*-phenyl phenol	60-150	60-150	140	84-210
or trichlorobenzene	60-150	60-150	3	2-5
or biphenyl (atmospheric beck)	60-150	60-150	140	84-210
or butyl benzoate (pressure beck)	15-40	15-40	140	21-56
Disperse dye	5-40	0.2-1.5	5	0.05
Sequestrant (EDTA)	2.5-5	2.5-5	2	0.1-0.2
Acetic acid, 56 percent	20	11	35	4
or monosodium phosphate	20-30	20-30	0	0
or monosodium phosphate acetic acid, 56 percent (preferred)	5	3	35	1.5
Soda ash	50	50	0	0
Sodium hydrosulfite	10	10	22	2.2
Water		290,000		
Effluent-calculated:				
BOD	100-225 pounds (atmospheric beck); 33-70 (pressure beck)			
Total suspended solids	Indeterminate			
Total dissolved solids	80-90 pounds			
pH	6-8			
Color	Indeterminate			
Toxic materials	Orthophenyl phenol, trichlorobenzene			
Net effluent water	35 gal/lb goods (average)			

NOTES: Data given above refer to disperse dyeable fiber, but are essentially the same for cationic-dyed fiber.

Data refer to polyester knits, piece dyed, using regular or textured yarn. Package dyeing will use the same chemicals, but less water. For woven goods, size must be added—30 lbs sodium polyacrylate; output, 30 lbs; BOD, 0.3 lb.

Allow additional chemical and BOD output for goods to be reworked; assume 3-5 percent of fabric is reprocessed.

BOD outputs calculated from data given in *American Dyestuff Reporter*, pp. 39-42, August 29, 1966. A biodegradable anionic surfactant was assumed.

Source: Industrial Waste Studies Program, Textile Mill Products, May 1971, for EPA by A. D. Little, Inc., Cambridge, Mass., unpublished.

Haas, et al of Sun Oil Co., developed some basic data on biodegradation, fish toxicity, vapor pressure and other environmental aspects of certain dye carriers (19). Work such as this can help industry determine which carriers would be acceptable or harmful under given circumstances. Table 6-13 indicates fish toxicity found in their study (Sure Sol – 160 = alkylbenzene biphenyl; Sure Sol – 170 = polymethyl biphenyl; Sure Sol – 190 = alkyl-naphthalene).

Eslick reported that experiments were made with a series of formulations to ascertain whether carriers known to contain phenols could be eliminated (6). The tests showed such carriers could be removed, but about 30% more dyestuff and chemicals were required. This markedly

TABLE 6-12

VAT AND DISPERSE DYEING OF 50/50 COTTON/POLYESTER KNIT FABRICS INCLUDING SCOURING OR PARTIAL BLEACHING

(Production basis: 1,000 pounds goods)

Chemical throughputs	Input, pounds	Output, pounds	Unit BOD,lb/100 lb output	BOD output, pounds
Item:				
Vat dye	20.0	1.0	—	—
Disperse dye	7.5	0.375	5	0.02
Carrier	40.0	40.0	85	34.00
Monosodium phosphate	25.0	25.0	—	—
Dispersing agent	10.0	10.0	50	5.00
Sequestrant	5.0	5.0	50	2.50
Sodium hydrosulfite	25.0	25.0	22	5.50
Sodium perborate	5.0	5.0	—	—
Detergent	12.5	12.5	50	6.25
Natural impurities	25.0	25.0	50	12.50
Rework				2.6
Total				68.4
Effluent:				
BOD	68.4 pounds			
Total suspended solids	—			
Total dissolved solids	189			
pH	12			
Color	1.4 pounds			
Oil and grease	—			
Net effluent water	30 gal/lb goods			

Source: Industrial Waste Studies Program, Textile Mill Products, May 1971, for EPA by A. D. Little, Inc., Cambridge, Mass., unpublished.

increased the BOD, COD and costs of the formulation. The final solution was to locate a non-phenolic carrier to substitute in the original formulation.

Routine cleaning might be viewed by an environmental team. For example, a thermosol range steamer was degreased in one plant observed, and the grease and oils were discharged to the treatment system (9). Needless to say the treatment plant grease levels increased dramatically. Furthermore, grease slick could be seen in the clarifier weir overflow for months afterwards. Spreading of canvas during such cleaning is suggested. Isolation of the grease and separate disposal by incineration or landfill is indicated. Another plant experienced a similar grease discharge and found straw thrown into the equalization basin that absorbed the grease. The grease laden straw was raked out and burned (9).

TABLE 6-13
FISH TOXICITY

Substance tested	X Water solubility total* (mg/l)	Y Concentration fatal to 50% of fish in 96 hr (mg/l)	Hazard factor X/Y	Biodegradable	Sinks or floats
95% Biphenyl	1.8	1.5	1.2	Yes	Floats
Sure Sol-160	2.4	8	3	Yes	Floats
Sure Sol-170	17	1.5	11.3	Yes	Floats
Sure Sol-190	30	4	7.5	Yes	Floats
A. Coal-tar derived methyl-naphthalenes	110	30	3.6	Yes	Most sinks
B. Coar-tar derived methyl-naphthalenes	24	4	6	Yes	50-50
C. Petroleum derived methyl-naphthalenes	242	35	6.9	Yes	Sinks
Butyl benzoate	59	6	9.8	Yes	Sinks
Ortho'phenylphenol	200	20	10	Yes	Sinks
3-Methyl methylsalicylate	50,000	2	25,000	Yes	Sinks
1,2,4-Trichlorobenzene	16	2.5	6.4	No	Sinks
Perchlorcethylene	92	7	13	No	Sinks

*Parts per million parts of water (mg/l). These values were obtained from the analysis of the aqueous phase from which the serial dilutions were made.

American Thread routinely boils out seven high speed yarn dryers about once a quarter (6). The boil out bath is dropped into the waste treatment plant. Samples of the boil out baths were sent to a lab for analysis. The results showed 1200 ppm copper, 800 ppm zinc and 600 ppm chrome. This bath is now pumped into a tank and then transported to a chemical soak-away on company land.

Metal salts have generally not been seen to be troublesome in treatment systems. There are reports of those who have been able to segregate and hold wastes containing copper and chromium and use them again, with strengthening when required. On the other hand, scrap iron has been used to render copper salts innocuous, and bisulfite is commonly used to reduce chromium (3).

Stetson (ICI) gave a cogent argument for the use of pad-batch (cold) dyeing of cellulosics (20). In Stetson's experience, mills using the cold pad-batch system with high reactivity dyes have experienced flexibility advantages, low energy requirements, high color yield (less waste), high production speeds, substantial overall cost savings, etc. In view of the arguments made, a mill should consider the possible advantages of such methods when possible. The pad-batch system, Figure 6-17, utilizes a dyestuff and alkali tank, mixing tank and proportioning pump. The mix is then pumped to a pad unit which usually employs a hollow spacer to achieve a narrow passage for the fabric. Thus the volume of liquor is kept low: about 5 gallons. This ensures rapid turnover of liquor so that decomposition is kept to a minimum.

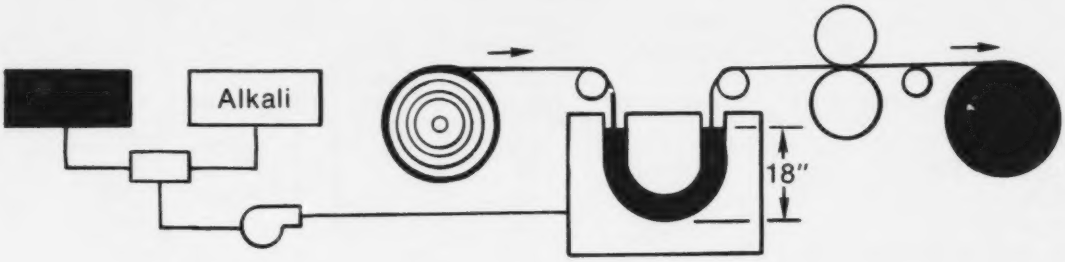


FIGURE 6-17

SCHEMATIC OF PAD-BATCH UNIT

The dyer and dye chemist might also critically examine methods used for dyeing blends where a two-bath process is now used; ways should be examined for converting to a one-bath or even a one-step process.

Perhaps the most radical proposal for reducing waste strength is to suggest that instead of accepting size "adulterant" and pollutant from greige mills, the size should be removed by the greige mill in the future. Transporation costs and cost for unnecessarily heavier fabric (and 5% weight of fabric) support the argument for this change. The idea will become even more rational in conjunction with advances in the development of solvent sizing and desizing. This would allow reuse of solvent soluble polymer size. In 1974 Dow and ICI were primary developers of this concept.

Focus is now given to the area of raw wool scouring. Soaps, synthetic detergents and soda ash have been used in scouring wool. It has been observed in alkaline scouring that soda ash combines with part of the wool grease to form natural soap thereby requiring less detergent. This has the advantage of lowering the waste strength, but is also said to lower recovered wool grease yields (3).

6.2.1 New Pollution-Free Solvent Wool Scouring Method

Two Belgian companies have developed a new method of scouring wool by solvent, which they claim is faster than classical wool washing, creates no pollution, and extracts large quantities of lanolin and fertilizer by-product.

The two companies – Le Solvent Belge (Verviers) and Extraction de Smet (Antwerp) – have formed a new company, Sover S.A., to promote the process. So far, it has sold one plant each in

Russia and Japan, for a total of $9.3 million. The first sale was made in December. Sover is also negotiating with firms in Poland, Austria, Yugoslavia, Uruguay, Brazil, Italy and the United Kingdom. The plants will be built by co-parent Extraction de Smet, an engineering consultant firm specializing in refining and extraction of fats and oils.

How It Works: Basically, the process removes from the wool all grease and suint (organic and mineral potassium salts accumulated from sheep sweat) by dissolving the compounds in water, isopropyl alcohol and hexane. Dirt on the wool is removed by spray jet pressure. The entire process is carried out in a hermetically sealed system that recycles the solvent mixture. At the same time, it collects lanolin and fertilizer. The lanolin is extracted in the hexane, and the fertilizer comes from the alcohol residual sludge.

Raw wool is spread out on a perforated steel belt. It is sprayed once with hexane, then five times with an aqueous alcohol solution at low spraying pressure, to avoid felting or matting down the wool. After each spraying, the wool is squeezed under rollers. The amount of alcohol used depends on the quality of the wool, but varies from 1 to 2 quarts per pound of wool.

Following the aqueous alcohol washing, the wool passes to two high-pressure hexane sprays for degreasing, each time being squeezed under rollers.

The wool then enters the dryer, where air, deoxygenated by oil burners and continually monitored for oxygen content, passes through it. Solvents left in the wool are recovered by the air-induced evaporation (thus the need for deoxygenated air and a hermetically sealed unit to prevent explosions).

The solvent mixtures are recirculated through a separator, where three phases form: the top layer of hexane enriched with the dissolved grease; an intermediate layer of insoluble impurities; and a bottom layer of alcohol, water, soaps and suint. The three layers are continuously drawn off for treatment.

6.2.2 Wool Piece Scouring and pH

In wool piece scouring plants, studies have indicated pH spreads of 2.5 to 10 (3). The variance was explained as intermittent discharges from sulfuric acid carbonizing. In such instances, it is suggested that equalization or neutralization tanks be used to blend periodic discharges from acid and alkali processing operations. In scouring woolen piece goods, whether in yarn or piece form, the main contents of discharges are soaps or detergents, lubricants, and dirt; this applies whether solvent or aqueous scouring techniques are used. Soaps can be "cracked" by strong mineral acids while soft detergents are now usually relatively completely biodegradable although there have been difficulties in obtaining biodegradable non-ionic detergents. Self scouring oils, i.e., usually mineral oils or saponifiable scouring lubricants, create large amounts of effluent with high solids content. Careful regulation of soda ash quantitites for scouring and neutralization of acid from carbonizing can lower the sulfate content. Avoidance of greasy carbonizing, acid milling and acid bleaching can also help. The sometimes excessive amounts of soda ash used in scouring or alkaline bleaching may cause the pH to rise to unacceptable levels and formulations should be reviewed (3), (21).

It has been noted that relatively recently new fiber lubricants have come onto the market claiming full biodegradability. These are mainly water-soluble. Since they are often applied at very low levels, they do not interfere with the milling processes. The use of such products could reduce water consumption, while at the same time lowering the sulfate and solids content of discharges from scouring and milling (21).

In wool dyeing with acid dyestuffs, the level of sulfates discharged can depend on control of the amount of Glauber's salt used. It has been observed that as much as 20% o.w.f. has been widely used. The use of 10% o.w.f. is recommended and should be examined (21).

Raising, softening and certain shrink-resist processes should produce little if any effluent if they are applied by padding without any rinsing process.

Polyvinyl alcohol has become the most commonly used sizing agent for fibers such as cotton and polyester. Proper selection of the grade of PVOH can greatly facilitate its removal in desize operations. Furthermore, "rapid desizing" using a peroxide-caustic soda combination at elevated temperature may provide better and faster size removal using less equipment and energy (22). This procedure reduces waste strength and provides a more easily biodegradable waste. Fully hydrolyzed grades of PVOH produce fibers that are stronger and tougher than partially hydrolyzed grades, but require large amounts of hot water close to the boil to remove the size. Although more expensive partially-hydrolyzed grades have lower tensile strength and produce more foam, they are more easily soluble in warm water. Obviously then, proper selection of the grade of PVOH is important. Next, the traditional method of removal requires use of large quantities of hot water in the early removal stages. This is due to the high viscosity of the PVOH tending to gel during early removal stages. Furthermore, accumulation in the washers, which can cause redeposition on the fabric, is occasionally overcome by continuous overflowing. A more practical method which overcomes these problems is to use hydrogen peroxide to decompose the PVOH. However, peroxide by itself requires steaming for effective removals. The use of caustic in a two bath system with peroxide has been shown to produce a thorough rapid continuous desizing. The conditions in the first bath include 0.8% H_2O_2, pH 6.5, and 194° F. The second bath includes 0.5% NaOH at 194° F. Wash water at 159° F is recommended. One bath system, using caustic and peroxide at 160° F followed by steaming, recuperator and countercurrent washing at 160° F, has also proven successful on certain blend materials. Another successful desize may be accomplished using 1% caustic at 160° F followed by a steamer, recuperator and wash boxes.

A novel approach to PVOH desizing involves "plasma" treatment (23). Low energy excited oxygen gas (plasma) was reported in 1973 to convert up to 60% of PVOH size on 50/50 polyester/cotton to harmless gases. When washed with water at ambient temperature, 95% of the PVOH was removed. The proposed process is shown in Figure 6-18.

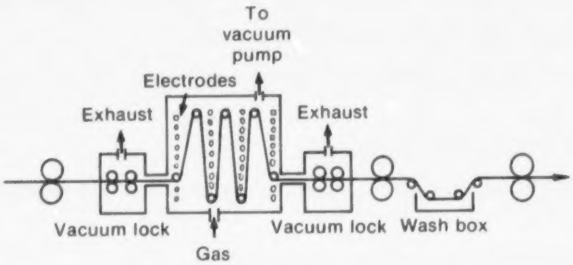


FIGURE 6-18

PROPOSED PROCESS FOR CONTINUOUS PLASMA TREATMENT OF TEXTILES

This system has not gained commercial acceptance, but it offers the potential, with further research and development, of being a desizing method which could contribute considerably to "zero discharge" requirements.

Table 6-14 compares starch waste degradability with PVA waste. Early work with unacclimated organisms suggested PVA was hardly degraded and could replace high BOD starch. Recent work indicates PVA can indeed be broken down to exhibit a high BOD. PVA is also high in COD (4).

Before leaving the area of size, starch overuse as a size should be mentioned. A study of cotton mills showed from 2 to 24% starch used on the weight of yarn (9). While most of the concentrations were justified, the major reasons for overuse were the lack of control of the relationship between relative humidity and the amount of size required. For example, 85% RH can require considerably more starch than at 65% RH.

In summary, the importance of waste strength reduction is obvious in that not only are the costs of treating wastes minimized, but also there will be savings in the costs of supplies. It is easy to see that any savings from such remedial measures can go a long way toward paying for the cost of waste treatment.

6.2.3 Waste Strength Reduction Checklist

- Institute dry clean up of dry chemical spills
- Display positive attitude posters to remind workers to stay alert.
- Consider segregating styles into groups with different formulations for each group; prevent "overkill."

- Carefully calculate mix sizes to accommodate only the fabric lot sizes to be run.
- Consider automatic feed-in of chemicals on continuous ranges.
- Consider segregating print pastes, greases and solvent wastes to separate treatment.
- Study reducing overusage of surfactants and cheap salts.
- Consider wet process monitors to check coating depths to prevent wastage and ensure a uniform product.
- Consider fiber and lint removal by screening.
- Consider requiring purchasing to request certificates of content on all chemicals bought.
- Consider minimizing use of carriers by equipment substitution.
- Consider reducing processing sequences by combining processes.
- Consider holding wastes which can provide neutralization.

TABLE 6-14

COMPARISON OF BOD LOADS OF STARCH AND PVA SIZING

Enzyme starch desizing of 100-percent cotton-woven goods (60 percent warp)

[Production basis: 1000 pounds greige goods (containing 5 percent water), starch loading 14 percent based on warp]

Chemical throughputs	Input, pounds	Output, pounds	Unit BOD, lb/100 lb output %	BOD output, pounds
Item:				
Starch	84.0	84.0	50	42.0
Fats and wax	4.4	4.4	80	3.2
Oil	0.4	0.4	80	0.3
Enzyme	1.6	1.6	2	—
Salt	2.5	2.5	—	—
Wetting agent	1.0	1.0	—	—
Suspended solids		5	2	0.1
Water		12,500	—	—
Total				45.6
Effluent:				
BOD	45.6 pounds			
Total suspended solids	89.0 pounds			
Total dissolved solids	5.1 pounds			
pH	6-8			
Color	—			
Oil and grease	4.8 pounds			
Toxic materials	—			
Net effluent water	1.5 gal/lb goods			

(Continued)

TABLE 6-14 (con't)

Polyvinyl alcohol desizing of 100-percent cotton-woven goods (60 percent warp)
[Production basis: 1,000 pounds greige goods]

Chemical throughputs	Input, pounds	Output, pounds	Unit BOD, lb/100 lb output%	BOD output, pounds
Item:				
Polyvinyl alcohol	48.0	48.0	1	0.48
Wax	2.4	2.4	80	1.92
Oil	—	—	—	—
Suspended solids	—	5.0	2.0	0.10
Water	—	12,500	—	—
Total				2.50
Effluent:				
BOD	2.50 pounds			
Total suspended solids	5.0 pounds			
Total dissolved solids	48.0 pounds			
pH	6-8			
Color	—			
Oil and grease	2.4 pounds			
Toxic materials	—			
Net effluent water	1.5 gal/lb goods			

Source: Industrial Waste Studies Program, Textile Mill Products, May 1971, for EPA by A. D. Little, Inc., Cambridge, Mass., unpublished.

6.3 Waste and Water Recovery and Reuse

There is no doubt that future prospects for water supplies in certain areas of the U.S. will depend heavily on the creation of a situation in which water can be reused and where chemicals can be reused. To those who might argue that the reuse of water means a reduction in quality, the following consideration is offered. The total flow of the River Thames is already being used one and a half times before it reaches London Bridge, and some of its waters are being used several times, having been extracted, treated, used, discharged to sewage works, and thence to the river repeatedly (3). In terms of chemical recovery, many chemicals in textile operations remain as relatively "pure" (unreacted) wastes, which indicates good potential for recovery and reuse.

In order to accomplish waste recovery and water reuse we need to enlarge our perspectives and reassess our thinking. There are no simple answers, and the real contributions will be made by textile engineers and chemists. It is from within that the real expertise for the future must come. Management's motivation is also very critical. Otherwise, the options are clear – continue to add-on more cost technology and pay more operational costs. At this time, the major task is seen to be in making better use of available personnel. The predominant attitude, or philosophy, is to let the treatment plant handle waste problems. However, there are some individuals in each organization who believe that a discharge of 10,000 lb COD/day represents excessive waste, and that opportunities for by-product recovery can and do exist. The first task of reassessment is to identify interested, knowledgeable people and let them identify interfaces where opportunities for reclamation, substitution or less usage might take place. However, before they can suitably perform their task, they need more exposure to information describing what is available and what it takes to get the job done. Only then can the resourcefulness and ingenuity of those interested people be fully utilized.

In conjunction with encouraging those who are interested and who presumably are the readers of this manual, the end-of-the-pipe philosophy should be supplanted by involving all key personnel through individualistic responsibility. This might easily be accomplished by the devising of material balances for each major production area discharge point. In this way, production people can readily see what is wasted, what causes problems downstream, what needs substituting, and what might profitably be considered for recovery.

To indicate just how great the potential for reuse may be, the summary of a recent study in the U.K. between a West Riding Local Authority (Wira), and the Department of the Environment, to study the possibility of using the outfall from a domestic sewage plant for all the process water of a local woolen mill is reproduced below (3):

> The textile chemist may think this is a foolish dream because of the very stringent requirements that he traditionally places on the quality of his process water. But the results of analyses of 1,000 samples of water used in the U.K. wool textile industry, and the assessments of the industry's water chemists as to whether suitable 'as is' or unsuitable without further treatment, show no agreement in many properties and there are obvious and very wide tolerances in the quality of water that can be used successfully.
>
> The outfall from the sewage works meets the average of this analysis except for turbidity, colour and suspended solids. We believed that the turbidity and colour might be acceptable. We reduced the solids content by installing a re-circulating sand filter at the sewage works, and we treated the outfall with gaseous chlorine to achieve an acceptable standard of sterility.

Initial trials on a laboratory scale were very promising, and piping was installed to use this treated effluent as an alternative to mains water at each of the normal mill processes. Throughout the period of 18 months the use of this treated effluent has been gradually extended, with detailed chemical monitoring and subjective judgment of coloration to all the processes of piece scouring, milling, dyeing, washing off.

This mill produces a substantial proportion of the blazer cloth made in the UK covering a complete range of weights and qualities; in particular it produces a wide range of colours from very light pastel shades for ladies' wear to dark meltons for industrial clothing, and it uses a wide range of dyestuffs representative of all those used by this sector of the industry. The mill staff, including the very particular cloth inspector, have found it impossible to tell which cloths have been processed with which source of water.

Following this technological success the local authority has now made arrangements to install a full-scale tertiary treatment plant at the sewage works output; the water will then be chlorinated, stored and piped to the mill to meet all its process requirements.

The mill uses some 200,000 gallons per day at a charge of approximately 25p per 1,000 gallons. This will be reduced to less than 5p per 1,000 by the new supply, a saving of £40 per day.

Water of a relatively "pure" nature can be collected and reused directly. Much of it may be hot water. Such sources include condensate water from high pressure lines, drying units, sizing machines, calenders, caustic recovery, etc. It is a reasonable estimate that between 40 and 70% condensate water can be easily reclaimed from the steam generated from boilers. Also, various cooling waters from compressors, hydraulic drives, evaporators, dye becks, etc., can be reclaimed. Water from suction slots or hydroextractors can also be returned to wash boxes. Two carpet mills reuse acid dye water decolorized by chlorine (Hollytex, California; Salem, Georgia).

6.3.1 Beck Cooling Water Savings

A simplified example based on an actual plant study of dye becks (10 becks) cooling water reclamation and savings is outlined below (9):

Flow Average	60 gal/min
Normal Cool Down Time (average)	45 minutes
Add Cool Down Time (average)	30 minutes
Boil Out Cool Down Time (average)	25 minutes

- Water Savings – normal cool down:
  45 min/day x 60 gal/min x 20 cycles/day = 54,000 gal/day

- Water Savings – add cool down:
  30 min/day x 60 gal/min x 20 cycles/day = 42,000 gal/day

- Water Savings – boil out cool down:
  25 min/day x 60 gal/min x 0.2 cycles/day = 300 gal/day

- Water Savings – total:
  54,000 + 42,000 + 300 = 96,300 gal/day

- Steam Savings
  Recover 96,300 gal @ 180° F - 60° F = ΔT 120° F.
  or $\frac{96{,}300 \times 8.33 \times 120^\circ}{856 \text{ BTU/lb.}} = 112{,}000$ lb. steam/day

- Dollar Savings

  1) oil – 112,000 lbs. steam/day x $3.00/1,000 = $336/day (72 days)

  2) natural gas – 112,000 x $1.00/1,000 = $112/day (240 days)

  3) water saving – 112,000 x $0.20/1,000 gal = $22/day (350 days)

  4) waste treatment saving – 112,000 x $0.25/1,000 gal = $28/day (350 days)

In this plant it was seen that a savings of approximately $68,500/year might be realized. Note water costs are given as $0.20/1000 gal and wastewater treatment costs are given as $0.25/1000 gal.

6.3.2 Case Histories

One vendor offers what is relatively expensive fiber and suspended particle filter/heat exchanger (24). The unit does not remove dissolved solids, i.e., salts, ionic dyes, surfactants, etc. Capacity is around 100 GPM with automatic self cleaning. It is designed to feed clean, hot water back into a washer. Effluent discharge temperature may be reduced from 180 to 100° F, water usage down to 70% and heat usage down to 85%. The system is shown in Figure 6-19.

Burlington Engineering is one company that offers a hot water recovery system designed to recover the cooling water from pressure becks, jets, package and beam dyeing machines, and store it at a pre-set controlled temperature. The water may then be reused as make-up water or rinse water in wet finishing or dyeing equipment. The recovered water, heated by means of exchangers or coils, is collected in an accumulator tank and pumped automatically into a 10,500 gallon stainless steel holding tank. Here, the water is constantly circulated by pumps through heat exchangers to maintain a pre-set temperature.

6.3.2.1 Stafford

After printing at Stafford the knit goods go to a rinsing/finishing range (25). The rinsing section is comprised of a Daiwa "Vibro" washer and an American Laundry "Jet" washer. After rinsing in a relaxed state the water is collected in a tank beneath the washers and recycled before going to treatment.

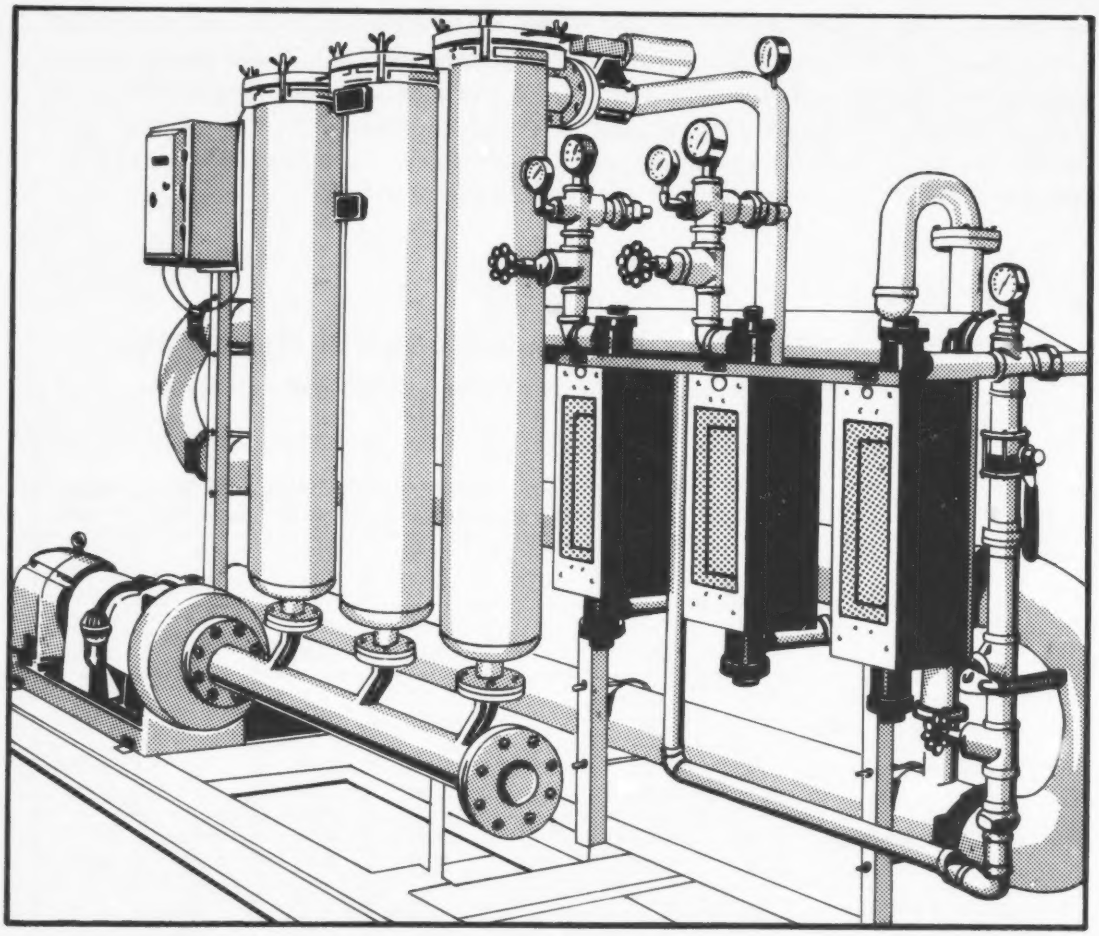


FIGURE 6-19

FHR SYSTEM

6.3.2.2 Cone Mills

Cooling water that does not come in contact with cloth or have excess chemicals added is used as a final rinse in dyeing (4). Cooling water in a hydrosulfite operation is reused as indigo wash water. In printing, cooling water is reused to wash blankets or back greiges.

Alspaugh pointed out, during an EPA Technology Transfer Seminar (Atlanta, 1973) that a fertile area for research exists in water reuse. He cautioned, however, that without top management's backing, operating personnel regard suggestions as outside interference, and nothing constructive is accomplished. One of the important questions that requires an answer before generally effective water reuse can be accomplished deals with water quality. Alspaugh writes, "Unless the minimum level of water quality necessary for processing is known, no effective program of reuse is practical (4)." Also a collection of tables in this same seminar indicated diverse opinion regarding tolerable limits of various substances before water can be reused. Table 6-15 is a comprehensive study of the quality of water used (a) for wet processing in the wool industry, and (b) that considered unsuitable by industry (26). It is of interest to note that, for some of the factors tested, rejected waters (b) were better than those accepted (a).

TABLE 6-15

WATER QUALITY REQUIREMENTS IN WOOL WET PROCESSING

Quality of water (a) used and (b) rejected in the processing of wool textiles

		Raw wool scouring	Loose wool dyeing	Top dyeing	Hank scouring	Package dyeing	Piece scouring	Piece dyeing
Number of samples	a	33	25	15	15	13	64	46
	b	13	8	6	7	6	40	20
Turbidity (Formazin units)*	a		92		26	95		73
	b		357		162	89		255
Colour (Hazen units)*	a	18	33		12	43	27	26
	b	67	98		52	33	46	81
Iron (mg/litre)	a	0.70	0.26	0.50	0.18	0.65		0.30
	b	0.75	1.50	1.20	0.34	0.44		0.65
Manganese (mg/litre)	a	0.77	0.10	0.10	0.12	0.12	0.09	0.10
	b	0.18	0.26	0.05	0.15	0.15	0.19	0.28
Suspended solids (mg/litre)	a				2	2	3	4
	b				14	2	10	19
Total hardness (mg $CaCO_3$/litre)	a	40	40				60	60
	b	150	150				160	160
Alkalinity (mg $CaCO_3$/litre)	a	68	46	56	55	58	108	78
	b	90	56	88	69	223	107	82

*The higher the value, the poorer the quality of the water

It has been stated that it would be ill-advised to state unequivocally what the optimum quality for wet processing plant water should be (4). The experience and judgment of the water chemist, the plant chemist, the dye chemist, and the dyer, are suggested to be best suited in each individual case to determine at what level a contaminant may be troublesome. Tolerances can only be set with a good knowledge of current operations and processes.

The following rough guide suggests the quality of water required for textile operations:

BLEACHING	– no color, no metals to catalyze the decomposition of bleach or interfere with dyeing, no high concentrations of organic (oxidizable) material to cause dye resists, moderate levels of salts tolerable.
DYEING	– pastels – no color or metal ions to affect shade, moderate quantities of salt tolerated generally.
	– dark – some color allowed, salts probably plateau with make-up water.
FINISHING	– requires little water, use fresh.

6.3.2.3 Textile Research Associations

A wool piece scouring operation was closely studied in the U.K. (3). The results indicated that a large proportion of water used during a single washing was still of reasonable quality for reuse. Figure 6-20 indicates, in the graph on the right, that after 1000 gallons of wash-off water is used, the remainder contains very little oxidizable material, as shown by the permanganate number, and might be reused successfully.

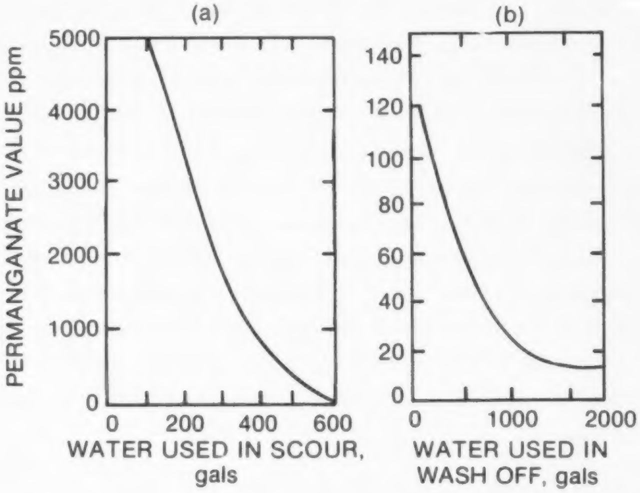


FIGURE 6-20

VARIATION IN PERMANGANATE VALUE WITH VOLUME OF WATER USED DURING (a) SCOUR AND (b) WASH OFF

Piping modifications were then made to the scouring machine, and a storage tank, valves, and a pump were added. Figure 6-21 shows the final arrangement. The reclaimed water is then used for the first part of the subsequent processing. Mains water is switched on for the final rinse and acts as make-up. No complaints were received from the dyeing department and the system is considered successful.

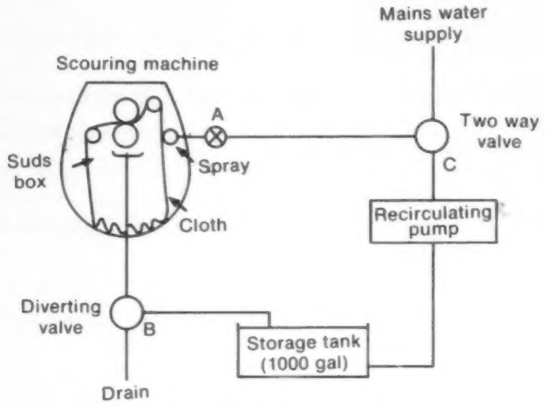


FIGURE 6-21

MODIFIED SCOURING DOLLY FOR REUSE OF WASH-OFF WATER

6.3.2.4 C.E. Bryan

Size recovery has received considerable attention over the past few years. Originally in the early 1950's CMC was substituted for starch as a means of reducing the high BOD_5 contribution of starch. Since then Carl E. Bryan (N.C. State) has performed elaborate investigations of processes for precipitating synthetic warp sizes (27). Aluminum sulfate was found to be most suitable for CMC recovery. Four cycles of CMC reuse were reported to give results equivalent to yarns sized with new CMC. Brown color observed in the recovered CMC indicated that natural impurities from cotton, and/or spinning oils from polyester may be retained on the yarn and in solution. However, performance was said not to be affected by these materials, and none was found retained by the yarns after desizing. Work was also conducted on PVA and starch precipitation, but no substantive recommendations resulted. During exploratory attempts to find a procedure for removing starch, modification of the molecule was attempted. Study of starch desizing wastes from two plants did, interestingly, indicate that enzymatically desized starch may not consist mostly of dextrose and other sugars of low molecular weight, as popularly thought. The starch although degraded was still found to consist of relatively high molecular weight polymers.

6.3.2.5 Gaston County

Perhaps one of the most sophisticated innovations to be introduced recently into the textile industry is the Gaston County PVA Reclamation System. During this seminar speakers from Gaston County, Clemson and J. P. Stevens described the system and its operational performance at J.P. Stevens Utica Mohawk plant. Approximately 1¼ million yards of sheeting were said to have been run at that time (28). Loom efficiency studies showed 10% virgin PVA added to 90% reclaimed could be selected, as mix ratios were not found to be critical. The flow chart in Figure 6-22 indicates the overall scheme. PVA must be kept as 1% concentration (1), for optimum efficiency, in the desize washer. Next, a vibrating screen (2) removes lint. After equalization (3) the ultrafiltration system (4) rejects concentrated PVA and returns hot water (5) back to the washer for reuse. Reclaimed PVA is stored (6) at 170° F and is reconstituted with 10% virgin PVA before reuseThe filtration system involves four "stages." The first stage concentrates to 3%, second to 6%, third to 8% and fourth to 10%. The reclaimed PVA was shown to have a brown color. Fabric samples, however, were shown to have barely noticeable color compared to virgin-sized fabric. This color was said to be no problem. However, colored or tinted yarn bleeding could be a distinct problem in this system. Capital costs for a 20 GPM system were said to be $300,000. A cost breakdown is given in Figure 6-23. The bactericide was found necessary because of biological growth occurring in the reclaimed size. Figure 6-24 shows the equipment in place at Utica Mohawk. In general, this equipment must still be given more time to demonstrate its capabilities clearly.

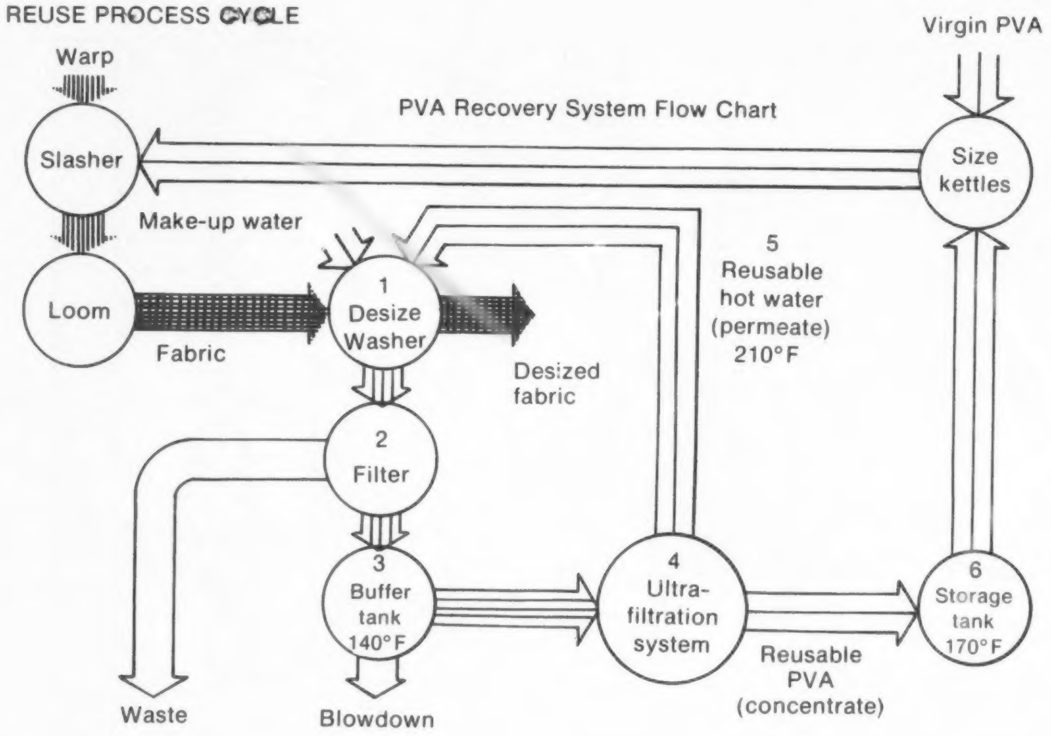

REUSE PROCESS CYCLE
Virgin PVA
Warp
PVA Recovery System Flow Chart
Slasher
Size kettles
Make-up water
5
Reusable hot water (permeate) 210°F
Loom
1 Desize Washer
Fabric
Desized fabric
2 Filter
3 Buffer tank 140°F
4 Ultra-filtration system
6 Storage tank 170°F
Reusable PVA (concentrate)
Waste
Blowdown

FIGURE 6-22

PVA RECOVERY SYSTEM FLOW CHART

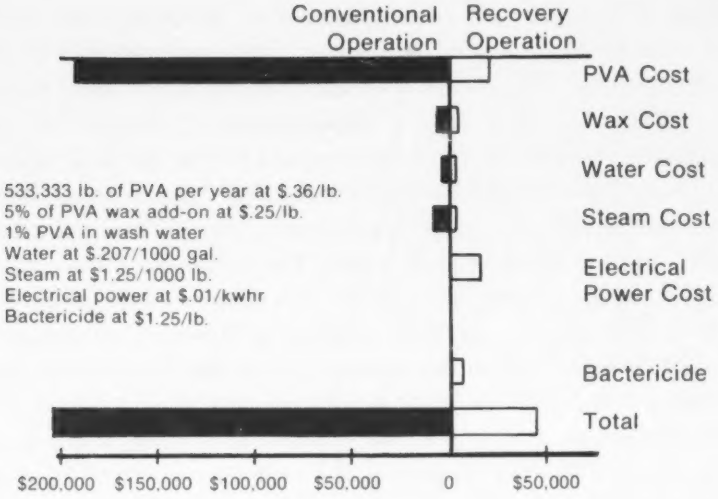


FIGURE 6-23

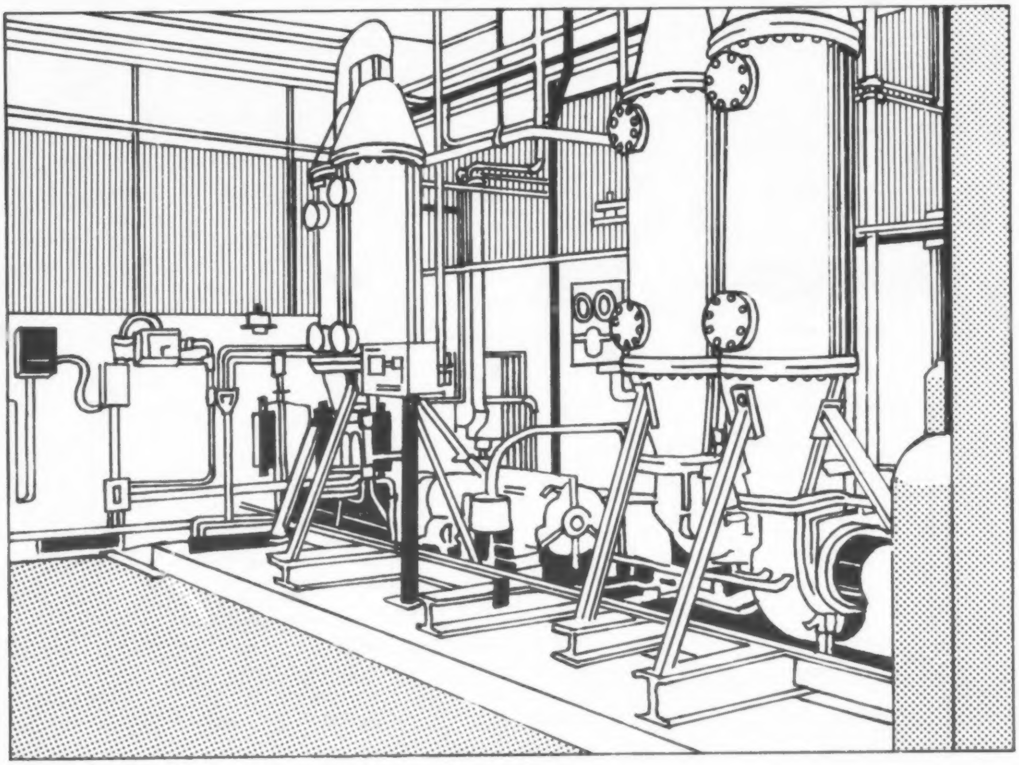


FIGURE 6-24

PVA RECLAMATION SYSTEM AT J. P. STEVENS UTICA MOHAWK PLANT

6.3.2.6 McCormick Mills

Hyperfiltration appears to be a practical approach to rejecting certain soluble and insoluble chemicals for reuse or disposal and providing good quality water for reuse in certain situations. A federally funded (EPA) project with Clemson and the South Carolina Textile Manufacturers Association has demonstrated this technology by mobile facilities transported to various mills in South Carolina (29). Such a system has special appeal in single shade dyehouses where dyes, heat and water can be reused. Hollow nylon fiber membranes were found to require excessive filtration procedures. Cellulose acetate membranes appear to perform better from a prefiltration standpoint but are temperature and pH sensitive. High-pressure (1000 psi) coated ceramic membranes and low-pressure (400 psi) cellulose acetate membranes are being studied currently for application (30). Hyperfiltration membranes produce water of lesser quality than produced by reverse osmosis. It must be said the cost may be high.

All reverse osmosis membranes used in desalting today, excluding developmental models, suffer from gradual compaction under pressure. This causes gradual deterioration in flux levels and often in salt rejection efficiency. In recognition of this most plants do not operate over 400 psi.

The recovery of spent mercerizing caustic is a practice with many-fold benefits. Reduction in use of raw materials due to product recovery from the waste stream is the major cost benefit. Lower waste treatment cost is another major benefit. In one plant 5% spent caustic averaging 100° F is stored before treatment in double effect evaporators. After the second stage, caustic is concentrated to approximately 30% at a temperature of 260° F. Settling in conical columns is the final step before reuse. Heat and water are reclaimed in the system. Adequate measures (screening, presettling, etc.) should be taken to prevent fibers or gelatinuous PVA from clogging such equipment (9). It has been suggested that if there is as much as 400 tons of sodium hydroxide available annually, at a minimum strength of 2%, recovery by evaporation for reuse may be economically feasible (31). However, other sources suggest that for economical concentration in a double or three state evaporation unit, feed should not drop below 4% (w/w NaOH) (32).

The treatment of textile effluents containing large quantities of grease presents special problems because wool grease and many of the traditional processing lubricants are not readily biodegraded. Even where recovery of wool grease is practiced, by centrifuging or acid cracking, residual grease present in treated liquor may be as high as 10,000 mg/1 and is unlikely to be less than 1000 mg/1. Additional treatment is, therefore, still required before the effluent can be discharged to a river.

Methods examined in detail at Wira for the treatment of effluent have resulted in the development of the Traflo-W process (Figure 6-25). The process essentially entails chemical coagulation of impurities followed by vacuum filtration, and, at its optimum, is capable of removing 100% of the suspended solids and grease and of reducing the BOD by at least 80%. Manufacture of this treatment plant is covered by a license agreement between Wira and Petrie & McNaught Ltd. (3).

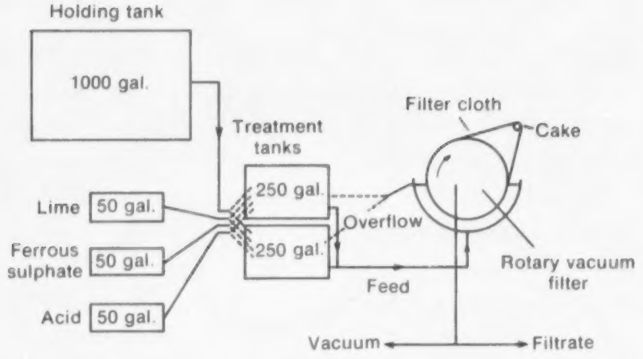

Holding tank
1000 gal.
Treatment tanks
250 gal.
250 gal.
Lime
50 gal.
Ferrous sulphate
50 gal.
Acid
50 gal.
Filter cloth
Cake
Overflow
Rotary vacuum filter
Feed
Vacuum
Filtrate

FIGURE 6-25

OUTLINE OF MILL-BASED PILOT-SCALE PLANT FOR TREATMENT OF PIECE-SCOURING EFFLUENT

In considering the recovery of wool grease, acid cracking is still widely used in the U.K. Figure 6-26 shows one process configuration in outline. This method is reasonably effective in producing a greasy sludge for separation from the mother-liquor. Grease from acid-cracking is usually dark brown and high in free fatty acid content. Efficiency varies in general from 50 to 70%. The cake usually contains 15 to 25% grease and up to 1.5% can still remain in the mother-liquor. The economics of such a process depend mainly on overall efficiency, labor costs, and the current price for the relatively low-quality grease. BOD_5 values are said lowered about one-third using this process (3).

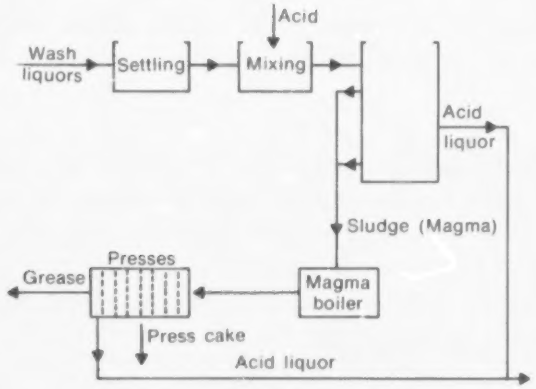

Acid
Wash liquors
Settling
Mixing
Acid liquor
Sludge (Magma)
Presses
Grease
Magma boiler
Press cake
Acid liquor

FIGURE 6-26

OUTLINE OF ACID CRACKING PROCESS FOR RECOVERY OF WOOL GREASE

Centrifuged grease, on the other hand, commands a higher market price than acid-cracked grease, but generally costs more to produce. Practically, efficiencies may run about 40% but can vary widely. The grease concentration is approximately 1 to 2% when it is taken from the scouring bowls. The concentration of grease is reduced to approximately 0.7% and is returned to the scouring bowl. The effluent can still contain about 7000 mg/l grease and the bulk of the organic matter. An example of a general arrangement for centrifugal separation is shown in Figure 6-27 (3).

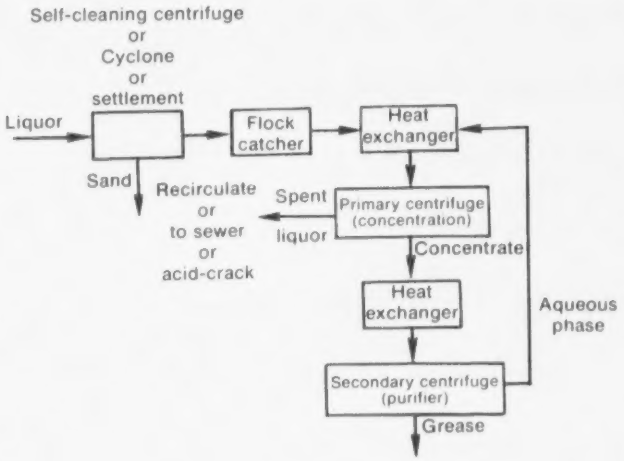

Self-cleaning centrifuge
or
Cyclone
or
settlement
Liquor
Flock catcher
Heat exchanger
Sand
Recirculate or to sewer or acid-crack
Spent liquor
Primary centrifuge (concentration)
Concentrate
Heat exchanger
Aqueous phase
Secondary centrifuge (purifier)
Grease

FIGURE 6-27

OUTLINE OF GENERAL ARRANGEMENT FOR CENTRIFUGAL SEPARATION

Chances of woolen piece or yarn scouring mills gaining profitable return from recovered grease are considerably less than where raw wool is scoured. Costs of segregation of waste streams with separate treatment, and poor quality grease containing varying amounts of free fatty acids, are some of the reasons.

6.3.3 Waste and Water Recovery and Reuse Checklist

- Consider total treatment for water reuse
- Reuse cooling waters directly
- Reuse condensate waters directly
- Consider filtration before reuse
- Organize in-plant team and establish water quality criteria

- Determine piping changes, storage costs, and pumping costs
- Determine where economy exists if on contract with municipality
- Determine whether increase in load to waste treatment will accompany flow reduction
- Can reclaimed water be used for preliminary equipment cleaning?
- Can bleach rinses be reused in scouring?
- Consider investigating solvent sizing and desizing
- Consider PVA size recovery and reuse
- Consider recovery of carpet-backing latices
- Consider application of hyperfiltration equipment
- Consider recovery of mercerizing liquors
- Consider recovery of wool grease
- Consider using air washer overflow in flushing or washing of toilets
- Consider suction slot extraction after last wash box with return of water to washer
- Consider returning vacuum water seal, or packing gland water to wash box

6.4 Chemical Substitution

In 1956 Masselli saw that the textile industry could quickly reduce its pollution load by 40 to 70% using substituion practices (2). However, pollution at that time was mainly a matter of BOD_5. Since the 1950's additional pollution parameters have continually been added to a list which makes a clearly defined goal difficult at this time. It should be more accurate then to assume that chemical substitutions will also take place for continually changing reasons. Since what is important now may have changing importance in the future, the suggestions in this subsection appear in a more or less randomized listing.

At this time one may substitute chemicals in processing for the following reasons:

1. To provide a more easily treated chemical by the treatment system in use. Consider the consequences of flow reductions occurring while waste strength remains high.

2. To provide a more easily recoverable chemical by reclamation equipment.

3. To provide for shortages in supply of chemicals (ex., disperse dyes based on anthraquinone reported in short supply).

4. To reduce the possibility or effects, of toxic chemicals harming the treatment system or environment (including ultimate disposal techniques or discharge of treated effluent).

5. To reduce a high pollution parameter to within permit requirements.

6. To replace materials in the waste which leave residues after treatment that may be undesirable in the receiving stream.

7. To provide a less costly chemical, one which increases processing efficiency or one that consumes less energy during processing.

6.4.1 Chemical BOD_5 Lists

In terms of BOD_5 characteristics of textile chemicals, the classical document useful in a substitution program would be the AATCC Committee RA58's listing which appeared in the American Dyestuff Report, August 29, 1966. A more detailed version of cotton finishing chemical BOD's was provided by Masselli and Burford (Table 6-16).

Other tables are provided in the EPA Transfer Technology Manual, In-Plant Control of Pollution, Upgrading Textile Operations to Reduce Pollution, EPA-625/3-74-004 (33).

6.4.2 Size Substitution

In view of the high BOD_5 load imposed on a treatment system by starch desizing, the substitution of this material by others with lesser pollution load may be considered. It should first be stated that prehydrolyzed, low viscosity modified starches possess better penetration and film formation than other types of starches available, and thereby reduce the quantity required for sizing. Substitution of water soluble cellulose ethers such as the low BOD_5 CMC for starch can still be rewarding under the proper circumstances. Refer to Subsection 6-3 for Dr. Carl Bryan's (N.C. State University) work on CMC reclamation and reuse (27). On the other hand PVA is used mainly for sizing cotton blends at this time. PVA reclamation has been discussed in the previous subsection also. One study indicates that one PVA brand has a COD of approximately 160% of its weight, while starch has a COD per unit weight of 100% (one pound starch exerts one pound of COD) (9). From Appendix 5-1-2 it can be seen that the COD of starch would amount to about 84 lbs., while that for PVA (at 160%) would be 77 lbs. of COD. This is a difference of 7 lbs COD/1000 lbs. goods in PVA's favor (note that the add-on basis compared is 8% PVA vs. 14% starch based on the warp).

TABLE 6-16

COTTON FINISHING PROCESS CHEMICALS, CONSUMPTION AND BOD[1]

Chemical	Amount used, lb. / 1000 lb. goods	BOD, %[2]	BOD lb. / 1000 lb. goods
B-2 Gum	22	61	13.4
Wheat Starch	16	55	8.8
Pearl Cornstarch	14	50	7.0
Brytex Gum No. 745	4	61	2.4
KD Gum	4	57	2.3
Slashing Starch	96*	—	53.0
Total	150	—	86.9
Carboxymethyl Cellulose	—	3	—
Hydroxyethyl Cellulose	—	3	—
Tallow Soap	20-100	55**	11-55
Nacconal NR	1	4	0.04
Ultrawet 35 KX	—	0	0
Acetic Acid, 80%	27	52	14.0
Mixture of 18 Dyes	37	7	2.6
Cream Softener, 25%	20	39	7.8
Formaldehyde-bisulfite Condensate	14	27	3.8
Glycerin	3	64	1.9
Sodium Hydrosulfite	11	22	2.4
Urea	13	9	1.2
Finish T.S.	8	39	3.1
Kierpine Extra	5	61	3.1
Merpol B	4	44	1.8
Glucose	—	71	—
Gelatin	—	91	—
Caustic, 76%	118	***	***
Soda Ash	42	***	***
Ammonia	7	***	***
Potassium Carbonate	3	***	***
Trisodium Phosphate	2	***	***
Sodium Perborate	3	***	***
Sodium Silicate	6	***	***
Liquid Soda Bleach	4	***	***
Hydrogen Peroxide	5	***	***
Sodium Chloride	7	***	***
Sodium Dichromate	6	***	***
Sulfuric Acid	10	***	***
Hydrochloric Acid	6	***	***

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[1] From Masselli, Masselli, and Burford, *A Simplification of Textile Waste Survey and Treatment*, New England Interstate Water Pollution Control Commission, (1959) (2).

[2] Based on weight of chemical; for example, 1 lb. of B-2 gum (61% BOD) would require 0.61 lb. of oxygen for stabilization.

* Calculated from analytical survey.

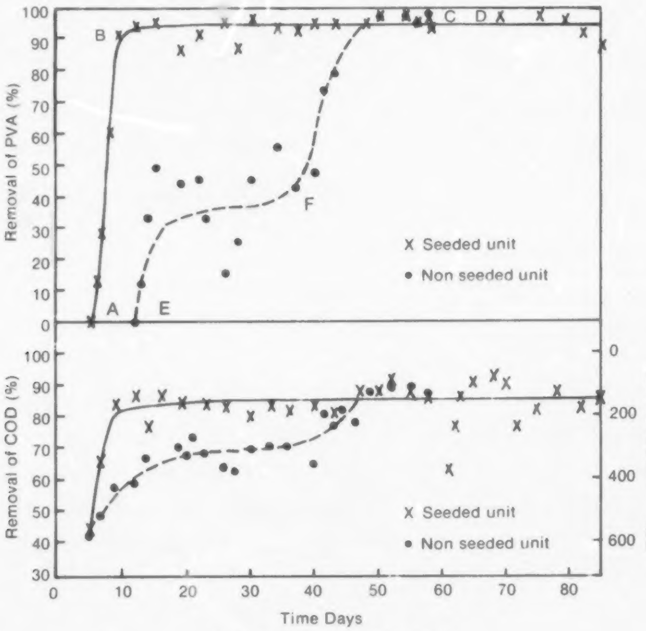
** Apparently contained high water content; dry soaps averaged 130 to 150% BOD.

*** Negligible BOD assumed.

At this point it should be mentioned that individual chemical COD values are conspicuous for their absence in the literature. This is because until fairly recently this parameter was of relatively little concern. It now ranks as a major concern, and a study similar to the previously mentioned AATCC BOD5 listing is awaited. Table 6-26 on page 6-70 provides a listing of textile chemical COD's using the Rapid COD method (34) (35).

6.4.3 Size Treatability

Since ease of treatability has been mentioned as a possible reason for substitution, the studies of Blair Mills, Belton, S.C., and Cone Mills are discussed (4). "Acclimated" organisms formed in Blair's treatment system were found capable of reducing PVA from 420 mg/l to nearly zero. When a 10% "seed" was added to Cone Mills pilot system, the PVA removal rate increased significantly within days. The following Figure 6-28 indicates PVA and COD removals by "acclimated" activated sludge treatment at Cone Mills.



C.D. PVA feed interrupted

FIGURE 6-28

REMOVAL OF PVA AND COD IN
CONE MILLS' PILOT ACTIVATED-SLUDGE UNITS

Barnhart compared the actual and potential treatability of starch and PVA wastewaters (36) (37). The results are indicated in Table 6-17. There are important considerations in achieving the potential extra reduction of PVA, one of which concerns sludge age. The specie of microorganism which degrades PVA was thought to grow at approximately 1/10th the rate of "normal" heterotrophic bacteria. In an aerated lagoon where the sludge age is the detention time of the system, the sludge may never reach the required detention time. In an activated sludge system, where 1/10th the sludge is wasted, most newly acclimated microorganisms may be wasted from the system. Another important aspect is that because the molecular weight of PVA is so large, (approximately 80,000-100,000) degradation becomes a long, time dependent process, and the degradation becomes an enzymatic function first rather than a biological assimilation function.

TABLE 6-17
SIZE EFFLUENT COMPARISON — COD

STARCH SIZE		PVA SIZE AND FINISHING OILS	
Inlet (Pounds)	75	Inlet (Pounds)	100
Effluent (Pounds)	10	Effluent (Pounds)	60
Possible further reduction in Biotreatment — minimal		Possible further reduction in Biological treatment 45 to 50 pounds. Minimum effluent value = 10 lbs.	

6.4.4 Foam Control

Before departing the area of treatment, the topic of foam needs to be touched on. Everyone is aware of the foaming problem, especially on prolonged cloudy winter days. Residual wetting agents are a large contributor towards this problem. Furthermore, studies of textile chemicals indicated that a commonly used anionic surfactant could exert as much as 140% of its weight in COD (1.4 lb. COD exerted per pound surfactant), and a commonly used non-ionic surfactant exerted over 200% of its weight in COD (34).

Barnhart showed (Table 6-18) a simplified dye solution analysis in 1975, which demonstrated that the amount of wetting agent used in processing would exit to a waste treatment plant in identical concentrations (37).

It becomes obvious that surfactants can constitute a large part of the COD, and ways to reduce usage and substitute surfactants should be explored. The BOD_5 problem of surfactants in respect to foaming was approached in the early 1960's. Since then so-called "hard" detergents have been replaced by so-called "soft" detergents. The facts are that even though the literature indicates that surfactants are more easily biodegradable than ever, they are still very difficult to degrade.

TABLE 6-18

DYE SOLUTION
(% as weight of cloth)

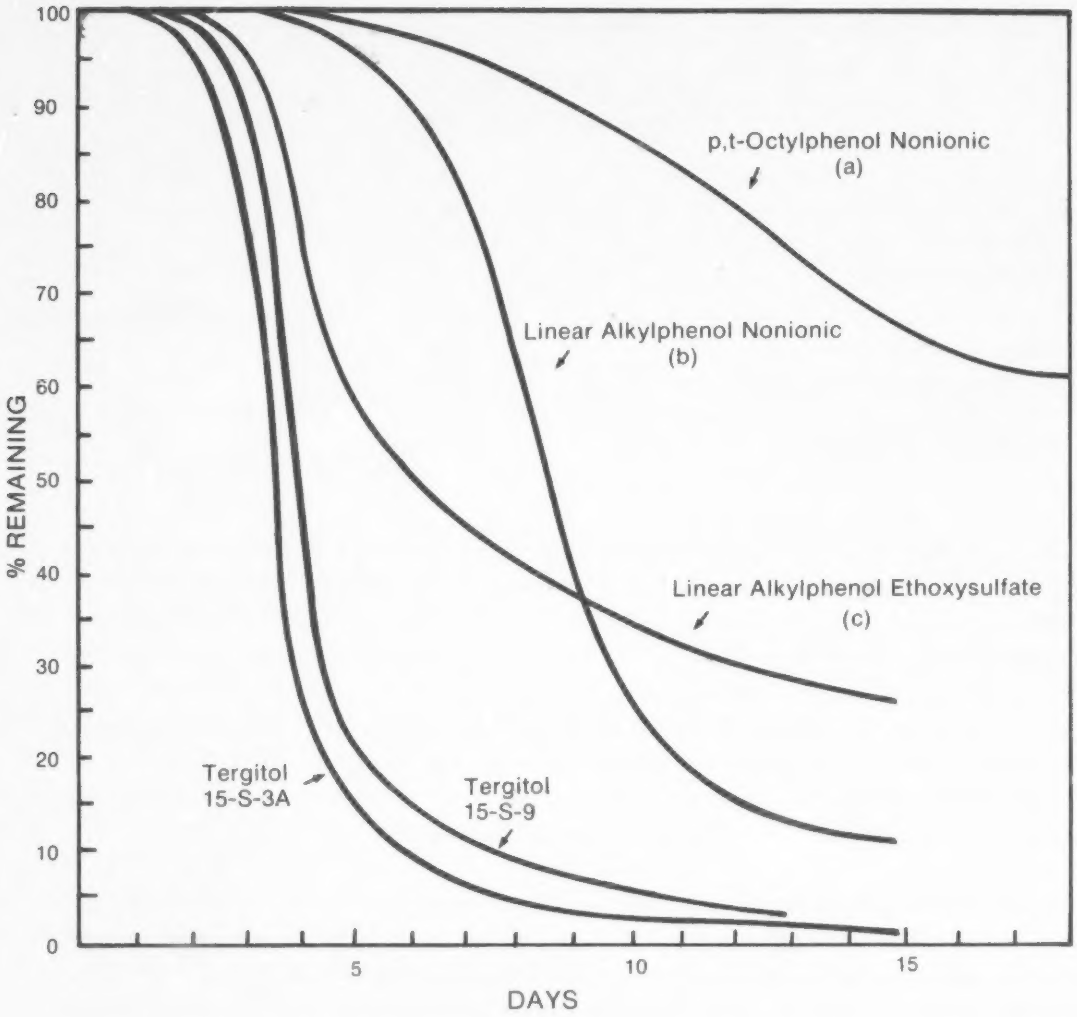
	In	Out
Carrier	3.0	3.0
Wetting Agents	0.5	0.5
Dye	0.5	-0.05
Salt	5.0	5.0*
Acid and Miscellaneous (non-organic acids)	1.0	1.0*

*No Impact on COD.

Adams (C.H. Patrick Co.) reported that linear alkyl derivatives tend to foam more than branched derivatives (38). However, they are also more readily and completely biodegradable than branched aliphatic or alkyl aryl types. Generally, 8 to 12 carbon hydrophobes give optimum wetting efficiency, while 16 to 18 is best for cotton detergency. Understanding how structure relates to properties, such as wetting, detergency and emulsification can help a mill select an optimum surfactant for a given job. For example, selection of a surfactant for a denim pad box would involve one that has maximum wetting ability and minimum detergency. Non-ionic surfactants with branching hydrophobes give superior wetting results over linear hydrophobe surfactants. (See also Tables 6-22 and 6-23 on pages 6-67 and 6-68).

Many surfactants, such as the alkylphenol ethoxylate and ethoxysulfate types, are resistant to attack by bacteria found in treatment systems and streams. Consequently such surfactants continue to foam and pollute natural waters and retard the efficiency of treatment systems. The River Die-Away test shown in Figure 6-29 (by Union Carbide) indicates what happens using low bacterial populations found in natural rivers under laboratory conditions. The Tergitol S series (linear alcohol ethoxylates and derivatives) of non-ionics degrade more rapdily than the other surfactants compared. Such a test coupled with foaming tests and performance application tests (wetting ability, leveling, scouring assistance, bleaching assistance, etc.) will indicate the optimal product for a specific application.

The River Die-Away test is conducted in an aerobic environment employing the low bacterial populations found in natural rivers. Consequently, fairly long periods are required for degradation. To conduct the test, 20 mg. of active surfactant were added to a one-liter sample of river water contained in a suitable bottle. The contents were mixed using a magnetic stirrer prior to sampling for methylene blue and cobalt thiocyanate activity. In between sampling, the flasks remained quiescent on a laboratory shelf at ambient temperature and light conditions. A loosely fitting rubber stopper was used to prevent excessive evaporation.



(a) Such as, "Igepal" CA-630 (General Aniline & Film): "Polytergent" G-3000 (Olin): "Triton" X-100 (Rohm & Haas):

(b) Such as, "Igepal" LO-630 (General Aniline & Film): "Sterox" MJB (Monsanto)

(c) Such as, "Alipal" LO-436 (General Aniline & Film)

NOTE: Nonylphenol derivitives: such as "Polytergent" B-300 (Olin): "Igepal" CO-630 (General Aniline & Film): "Triton" N-100 (Hohm & Haas): and TERGITOL Nonionic NPX, are similar to the actylphenols in biodegradability.

FIGURE 6-29

MEASUREMENT OF BIODEGRADATION BY THE RIVER DIE-AWAY TEST (Anionics by Methylene Blue; Nonionics by Cobalt Thiocyanate; 20 mg. per Liter Initial Concentration)

The results presented in Figure 6-29 indicate that the linear alcohol-derived ethoxylates degraded more rapidly and more completely than do the alkylphenol derived materials. Comparable foamability losses and surface tension recoveries were measured in the case of the linear alcohol ethoxylates; this loss-of-surfactancy was not found with the alkylphenol-based materials. (See Case History at end of subsection 6-4).

An interesting finding appeared in the February 1972 American Dyestuff Report.EPA investigators from Athens, Ga., found an 80-fold increase in p-nonylphenol between a carpet yarn mill's treatment influent and effluent. Their explanation was that the phenol increase was likely due to biological degradation of the surfactant.

6.4.5 Wool Fulling

Soap used in fulling can contribute high BOD levels (2). If detergents or sulfuric acid are used, the table below shows the BOD equivalent of a "hard" detergent (Lissapol N) and that of a "soft" detergent (Empilan KL10).

Chemical	*BOD equiv. (lb./lb.)*
Soap (textile flakes)	1.06
Lissapol N	0.06
Empilan KL10	0.72
Sulfuric acid	0

6.4.6 Carriers

The topic of carriers has been approached in subsections 6-1 and 6-3 (see Table 6-3, page 6-2 and Table 6-10, page 6-30 for a comparison of some carrier BOD's). These substances can be highly polluting and toxic. The use of high-pressure equipment, when possible, to reduce the concentration of these materials discharged, is strongly suggested. Table 6-18 indicates that the amount of carrier in a dye bath formulation exits in identical concentration to a waste treatment plant. Vendors at this time, the literature indicates, are developing carriers which are more susceptible to biodegradation and less toxic. These efforts should be vigorously encouraged. The user should know a great deal about the degradability and toxicity of any new chemicals. If the material is said to be susceptible to biodegradation, evidence should be produced showing how a typical waste treatment system removes it, before it reaches the receiving body of water. Furthermore, information on concentrations in wasted sludge should also be provided. If degradation is not complete, discussion on the chemicals' chances of building up in the food chain should be provided. Preliminary studies of toxic materials should indicate low, acute, and chronic toxicity values in animals, suggesting no hazard with normal usage. The chemical should be compared in reactivity to a standard. In use concentrations, it should be compared to regulations, such as California's Rule 66. Lastly, but not least, in terms of a carrier it should certainly produce a high color yield, no harmful effects on thermofixed goods, good effect on dye migration, and no harmful effects on lightfastness. It should also be readily emulsifiable, have good washfastness, give level dying, and have good abrasion resistance.

Another area of toxicity concerns chrome. Many vat and sulfur dye shades can be very satisfactorily oxidized by using peroxide over dichromate (9). Optimum fastness is achieved by maintaing the proper pH using peroxide oxidation. Study showed actual chemical cost was approximately half that for dichromate, using a peroxide concentration of 0.35%. Indications were that this concentration could be reduced considerably for many sulfur dyes. While automatic control of peroxide concentration (see Figure 6-13) is not a necessity, there can be advantages to the use of such equipment. In cases where dichromate or peroxide may not be suitable, sodium iodate or laking agents may be substituted. One mill experience indicated that substituting iodate for dichromate, in some instances, actually produced better absorbency and luster in their dyeing than dichromate.

6.4.7 Substitute for Acetic Acid in Dye Bath

Substitution of formic acid for acetic acid in dyeing gives a substantial reduction in BOD and, because of its lower equivalent weight, can give a cut in costs (2).

Chemical	*BOD equiv. (lb./lb.)*
Acetic acid	0.64
Formic acid	0.12

6.4.8 Dyeing Wool-Replace Acetic Acid

Masselli (2) demonstrated that in dyeing procedures using acetic acid, the acid may contribute 85% of the BOD_5. If ammonium sulfate is used in place of acetic acid, the BOD can be reduced the full 85%. Furthermore, the ammonium content will serve as a nutrient in the activated sludge process. Of course, the salt content of the waste will be increased.

6.4.9 Reactive Dyes

A relatively recent development in the area of dyeing is the improved range of reactive dyestuffs with shorter fixation time and higher yields, which may also result in less wastage to the drain.

6.4.10 Dye Selection

ICI addressed the topic of dye selection for the times in Textile Industries, July 1974. A related paper appeared later in the Textile Chemist and Colorist, January 1975, which emphasized energy conservation. The rationale suggested that enough potential existed for dyehouses to consider dyeing processes that can minimize energy consumption. The latter paper acknowledged that a dyer may not always be able to select a class of dyes which minimizes energy consumption, but once the choice is made, dictated by the customer's idea of end-use fastness, the dyer can select the method of application that minimizes the energy consumed in applying a given class of dye.

In considering package exhaust dyeing, Table 6-19 shows an idealized ranking of dyes by ICI. The table includes the energy required for dye application and subsequent clean up, but not the energy used in drying. Drying was assumed equal for all dye classes. The figures in the table require balancing against dye costs, level of redyes, and cost of application.

In discussing continuous dyeing methods, the pad-bath semi-continuous method is seen in Table 6-20 to have the lowest energy use of any method of dyeing cellulosic material. When washing is added the energy required is additive. Continuous methods of washing are suggested best.

Assuming 150,000 BTU/gallon fuel oil, costing can be estimated using Table 6-20. For example, the pad-dry chemical pad-steam method uses about 610,000 BTU/100 lb. goods dyed. The pad-dry method uses 90,000 BTU less. At 24 million pounds per year this could save approximately 160,000 gallons of fuel/year. At 20¢/gal. fuel this saves $32,000 at 30¢/gal. the savings are $48,000. (Figure 6-30 gives a larger perspective.)

TABLE 6-19
IDEAL ENERGY CONSUMPTION FOR PACKAGE EXHAUST DYEING[a]

Dye Class	Energy Consumption (BTU/100 lb)
Direct	2.0×10^5
Naphthol[b]	3.1×10^5
Vat	5.3×10^5
Fiber Reactive (High Reactivity)[c]	8.1×10^5
Fiber Reactive (Low Reactivity)[c]	8.5×10^5
Disperse (Atmospheric)[d]	4.6×10^5
Disperse (270°F)[d]	5.3×10^5
Acid	2.6×10^5

[a] Assumptions: Drying is not included and is assumed equal for all dye classes; 10:1 liquor ratio; ideal dyeing machine with no additional heat required after reaching dyeing and/or washing off temperature.

[b] Includes energy required to manufacture ice used during the dyeing operation at rate of 1.7 lb of ice/lb of goods.

[c] Aftertreated with a fixing agent.

[d] Reduction cleared.

TABLE 6-20

APPROXIMATE ENERGY CONSUMPTION OF COMMONLY USED CONTINUOUS SYSTEMS[a]

Method	Energy Consumption (BTU/100 lb)
Pad-Batch[b]	3.6×10^5
Pad-Dry	5.2×10^5
Pad-Dry-"Bake"	5.9×10^5
Pad-Dry-Chemical Pad-Steam	6.1×10^5
Pad-Dry-Thermofix-Chemical Pad-Steam	7.0×10^5

[a] Drying is not included and is assumed equal for all methods.
[b] Semicontinuous method.

6.4.11 Resin Selection

Vendors of resin/catalyst systems are currently advertising modified conventional resins and catalysts which will cure quickly at relatively low temperatures. Although no wide-spread application appears indicated at this time, there may be certain applications where these systems can provide advantageous substitutions and should be examined. In response to reported carcinoogenic effects of chloride catalysts, one firm reports switching to sulfate catalysts. This firm also reports favorable results with a glyoxal resin bath using hot catalysts such as metal salts of φ-hydroxy carboxylic acid to cure at lower temperatures and to save energy (39).

6.4.12 Oil and Lubricant Substitute

Carding oils and antistatic-lubricants might be replaced by mineral oils with non-ionic emulsifiers and other low-BOD substitutes according to Masselli (2).

6.4.13 Solvents and Print Pastes

Masselli reported that elimination of hydrocarbon solvent usage in print-paste makeup reduced the BOD load from 6,000 to 2,000 pounds per day in one mill (4). One or two barrels per day of hydrocarbon solvent may contribute as much as 1,000 to 2,000 pounds of BOD, and substitution of aqueous print pastes should be considered where possible.

6.4.14 Phosphates

If a reduction in phosphate is required, substitution of non-phosphate chemicals such as, ethylene-diaminetetra-acetic acid, and others, might be considered (4). Phosphate removal by chemical coagulants is readily accomplished and has been applied successfully before, during or after activated sludge treatment. Unless usage of high-phosphate containing flame retardants occurs, phosphates are generally not a problem.

6.4.15 Nitrogen

Although not anticipated to be a major problem in textile wastes (nitrogen is often added for nutrient benefit in textile waste treatment systems), nitrogen compounds are worthy of mention here in terms of future considerations. Nitrogen can occur in wastes as ammonia, nitrate, nitrite, and organic nitrogen. Flame retardants may be a major N source. Ammonia has a very high oxygen demand (423%) and can deplete oxygen resources in a stream given time (4). On the other hand, ammonia has a very high chlorine demand and may produce possibly toxic chlorinated amines (40). The well-known increase in algae blooms caused by nitrites and nitrates is also a problem. Dr. A.W. Lawrence (Cornell) discussed the elaborate biological treatment requirements necessary to reduce wastewater nitrogen (36). In some cases treatment might need to be doubled. It is apparent that if increases in nitrogen use occur in the industry, the process should be designed to utilize the compounds very efficiently.

6.4.16 Phenolics

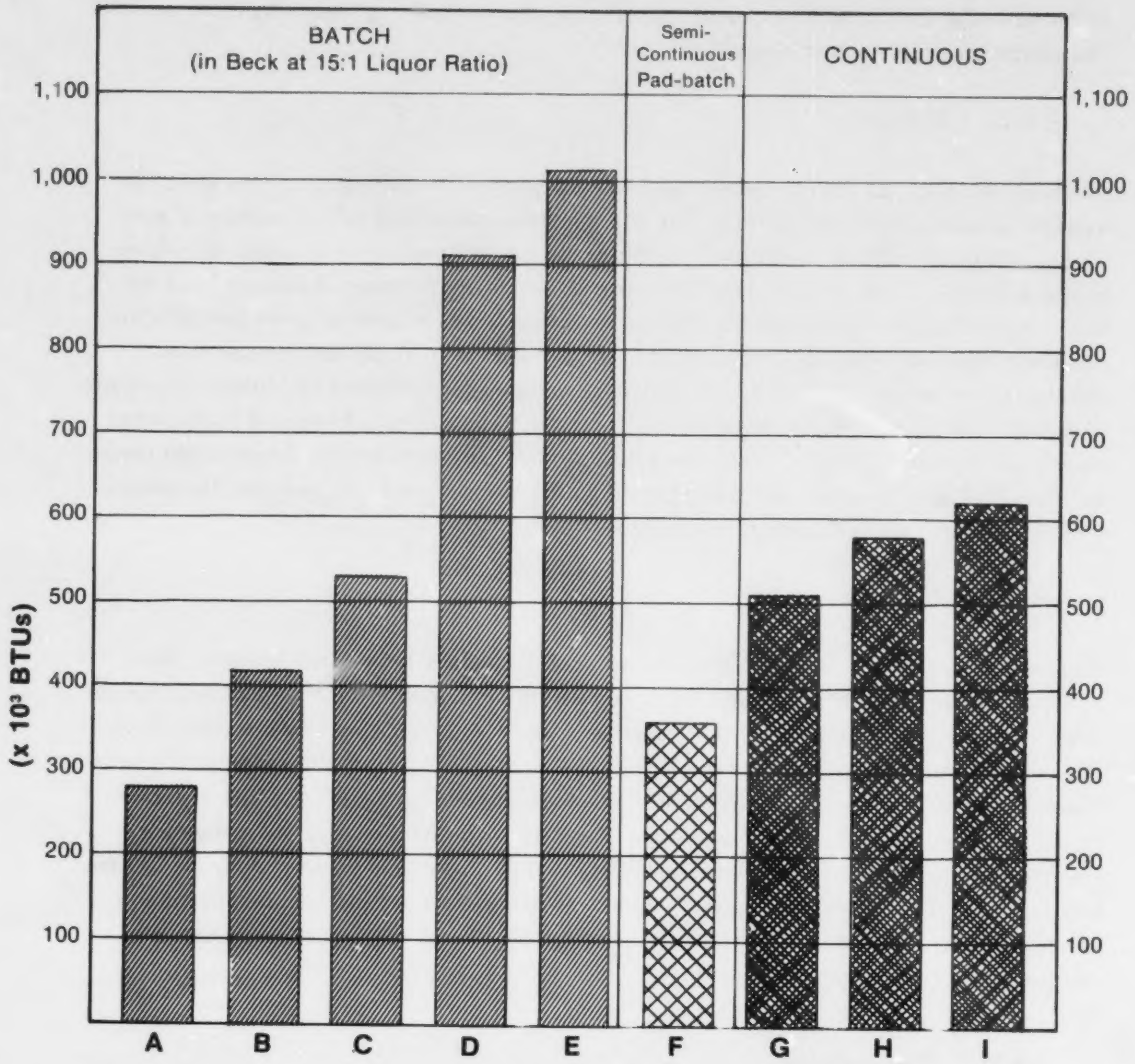
The common test for phenolics indicates compounds containing the phenol structure. Many textile chemicals can contain this structure. Some of the following have been identified: certain detergents, phenol-formaldehyde resins, carriers, solvents, lubricating oils, certain toilet bowl cleaners, etc. Substitution, if necessary, should be examined cautiously. For example, phenolics used in synthetic dyeing may be reduced in a formulation, but too great a reduction may require use of more dye and other auxiliaries. Solvents and used lubricating oils containing phenolics are occasionally disposed of down floor drains. This should be prevented, and is often easy to see by oil stains in the vicinity of a drain. Such chemicals, and also unused phenolic-formaldehyde resins (pad), may be collected, and, perhaps, sprayed on plant waste rags, etc., and incinerated (4), (6).

6.4.17 Wool Scouring

The use of alkaline scouring instead of neutral scouring of wool top has been said to convert some greases to soap and thereby reduce the amount of detergent needed. However, Wira chromatographic studies have confirmed that the composition of the residual wool grease after a neutral scour is different than that after a soap-soda ash scour. Possible effects in later processing must also be considered (3).

6.4.18 Ammonia Mercerization

J.P. Stevens' Technical Center investigators suggest that liquid ammonia treatment prior to durable press and flame-retarding finishes may be a viable approach to attain improved overall



BECK DYEING
A = Direct Dyes
B = Naphthols
C = After-treated Directs
D = High reactivity (low energy) fiber reactives; e.g. Procion MX, Levafix E, Remazol, Drimarene K
E = Lower reactivity fiber reactives; Reactone, Cibacron, Procion H, Drimaren X

PAD-BATCH, (Semi-continuous) PROCESS
F = Pad-Batch, applicable with low energy reactives: e.g. Procion MX

CONTINUOUS PROCESSES
G = Pad/Dry, for use with Procion MX (low energy reactives)
H = Pad/Dry/Bake, for most classes of reactive dyes
I = Pad/Dry/Chemical Pad/Steam, for vats, sulfurs or reactives

FIGURE 6-30
APPROXIMATE ENERGY REQUIREMENTS TO DYE 100 POUNDS OF FABRIC

fabric performance (41). Significant efforts have been made in the past several years to utilize the rapid swelling and plasticizing effects of liquid ammonia on cotton. These efforts have led to the Prograde process for treating sewing threads (42). Norwegian research workers explored the effects of liquid ammonia on cotton fabric (43). Improved luster, dye affinity, strength, and dimensional stability were in the range obtained by caustic mercerization. Furthermore, ammonia produced a softer hand improved resistance to wear and crease shedding compared to caustic. USDA workers disclosed a patent in 1973 for mercerization with liquid ammonia in a chainless mercerizer (44). In general, the better the easy-care performance of a garment, the worse its strength and durability.

The mechanical performance of DP fabrics are mainly governed by the fiber structure, the pretreatment, and the cross-linking treatment. On the other hand caustic mercerization performed today often imparts a superficial treatment as concerns are with good luster and color yield. Caustic mercerization in these cases may not give good fiber strength due to non-uniform treatment as a result of too short immersion time (high speeds), inadequate shrinkage of the fabric, and the poor wetting and penetrating power of strong caustic liquors. Under the conditions above, the potential application of ammonia treatment suggests itself as a future alternative to caustic mercerization. At this time, it should be said, work is still continuing to improve the technology. Furthermore, economical recovery of the ammonia must be demonstrated. It should also be mentioned that work is being conducted to ascertain whether conventional caustic mercerization can be improved. Steam, for example, is felt capable of reducing the surface tension of fabric, by replacing air in the fabric, before mercerizing. Trials using cotton print cloth indicate significant increases in strength may result compared to conventionally mercerized fabric (45). Another possible application of liquid ammonia, as a low pollution substitution for conventional caustic mercerization is being explored by a Norwegian firm. Heavy cotton treated with liquid ammonia gave better form and dimensional stability, gave less shrinkage during laundering, required less dye for a given depth of shade, and could be made shrinkfast on a Sanforizing machine. The hand was said to be better, and progressive shrinkage was virtually nil. However, the process is meant to be supplementary to and not a replacement for resin finishing.

Current development includes modifying machinery to reduce liquid ammonia uptake. Still as for its promise, the first commercial application of liquid ammonia processing will be installed by Burlington Industries' Erwin Mill. After four years of intensive research and development by the Sanforized Co., the process, trademarked Sanfor-Set, will process about 20 million pounds per year of 14 oz. cotton jean fabric. Fabrics will be trademarked "Duralized." The process schematic and operating factors are given in subsection 5.5, "Process Changes." Whether liquid ammonia will replace caustic mercerization cannot yet be foreseen as the process still awaits exploitation and development. Mr. C.C. Ware (Sanforized Co.) suggest that the luster from liquid ammonia may not be as great as with caustic soda (46). However, shrinkage stability, crease recovery, and smooth drying are said better. It is reasonable to assume that programs will be undertaken to assess the advantages in specific cases, where the features of ammonia-treated fabrics may be more desirable than caustic-mercerized fabrics.

6.4.19 Chemical Inventory

An inventory of chemical usage is the first step in substitution considerations for various reasons. A summary of annual chemical usage by one firm is given in Table 6-21, in which chemicals are ranked in terms of pounds used. Here the priority of carrier NT is established by usage. Inquiry may be made into the disposition of the chemical as it is discharged. What amount escapes to the air versus that discharged in the waste water? Table 6-22 provides additional information for substitution considerations. The information here, provided by Dow Chemical, should be encouraged by all vendors.

Two case histories may be helpful to indicate the potential of a program including chemical substitution. The first case is significant in that it took place before 1960.

6.4.20 In-Plant Textile Changes at Burlington

In-plant studies to reduce volume and pollution load of wastes at Burlington are summarized (47).

TABLE 6-21

EXAMPLE OF ANNUAL CHEMICAL USAGE, 1972

Rank	Chemical (type)[1]	Usage	
		Pounds	Percent
1	Carrier NT (B)	331,457	12.540
2	Neutrol #9 (C)	200,064	7.569
3	Aerotex water repellant 95 (D)	136,205	5.153
4	Cap LEV LSP (C)	132,685	5.020
5	Soap OFF 60 (A)	126,708	4.794
6	Acetic acid (E)	124,206	4.699
7	Neoport APO (B)	117,609	4.449
8	Solvecrest RB (A)	110,788	4.191
9	Monosodium phosphate (E)	92,672	3.506
10	Caustic soda (E)	89,673	3.393
11	Dispersing agent (C)	84,887	3.212
12	Avitone F (C)	72,443	2.741
13	Calgon (F)	69,130	2.615
14	Fanapon X70 (A)	58,198	2.202
15	Neoport DPG (B)	51,871	1.962
16	Raycofix NY (H)	48,428	1.832
17	Sanopan DTC (A)	47,227	1.787
18	Formic acid (E)	46,779	1.770
19	Sodium hydrosulfite (A)	45,983	1.740
20	Cap Carrier BB (B)	38,867	1.470
[illegible]1	Ammonium chloride (E)	38,189	1.445
[illegible]2	Herriton SWD (C)	36,698	1.388
23	Intrawite EBF (G)	30,242	1.144
24	Gluconic acid (C)	27,416	1.037
25	Tanalube RF (C)	24,654	0.933

[1] A = scour; B = carrier; C = dyeing assistant; D = finish; E = pH control chemicals; F = softener; G = fluorescent; H = fixing.

TABLE 6-22
ENVIRONMENTAL PROPERTIES OF BIPHENYL

Stability	
Flash Point °F	260
Chemical Reactivity	
Water	stable
Oxygen	stable
B.O.D. % Theoretical	
5 day	3
10 day	71
20 day	79
Movement	
Vapor Pressure, mm Hg at 25°C	0.008
Water Solubility, mg/l	7.5
Aeration Stripping, % C.O.D. removed after 4 hours	89
Bioconcentration	
Log P (Calculated)	4.1
Toxicity	
Acute	
Oral, LD_{50}, mg/kg for rats	1600-3000
Skin Irritation	very slight
Skin Absorption	may be absorbed slowly
Eye Irritation	moderate
Vapor Inhalation, TLV, ppm	0.2
Fish, LC_{50} for fathead minnows mg/l	5

Water usage was reduced by returning pump cooling water to the reservoir and by better control of the pressure water filter backwash. A program was put in effect to reduce the volume of water used in the various processes. This program evolved slowly because of the reluctance to change or to reduce any component of the operation, such as the elimination or reduction of various washing operations or the reuse of these wash waters in other processes. Reuse of certain wash waters in dyeing showed promise, but these methods of re-use were not studied further.

The pH of the waste was reduced by the installation of a caustic recovery unit. This unit has resulted in a significant reduction in the pH and hydroxyl alkalinity, making the waste more susceptible to biological action. The caustic recovery not only reduced the pollutants discharged into the stream, but also was a good investment by returning re-usable caustic soda to the process.

One of the major sources of BOD load was starch used in the warp sizing operation. Because of this, CMC (Carboxymethyl Cellulose) was evaluated as a replacement for the starch, and after nearly 15 months of studies and trials, methods were developed which permitted the substitution in the mill operation. While substitution of CMC for starch sizes resulted in an overall BOD reduction of about 50% for the entire mill operation, it was found somewhat more expensive than starch, and additional studies were made with combinations of CMC and low BOD starches in order to achieve the same BOD reduction at a lesser cost of sizing materials. This was successful.

Further studies of chemicals in the plant brought about the substitution of detergents for soaps, reducing the BOD of many individual samples by 70 to 80%. Some finishes were found to have less BOD than others, and, although the overall waste volume of finishes was relatively low, substitutions of finishes were made wherever practicable. Certain dyestuffs were given consideration because of low pollutional load, but studies were not carried to completion, Table 6-23.

TABLE 6-23
DATA REFLECTING IN-PLANT CHEMICAL SUBSTITUTION CHANGES

Item	Before Changes	After Changes	Reduction
Five-Day BOD	410 ppm	210 ppm	190 ppm
pH	11.5-12.0	10.0-10.5	2.0
Total Alkalinity	1600 ppm	560 ppm	1040 ppm
Hydroxyl Alkalinity	—	180 ppm	—
Carbonate Alkalinity	—	380 ppm	—

6.4.21 In-Plant Changes at United Piece Dyeworks

This case, described by Randall (VPI) involves excessive foaming which washed solids onto the sides of the lagoon, retarding efficient treatment (4). Initially, the system discharged 1 MGD into a 3.25 MG aeration basin. The system began with 44 hp/MG applied which was inadequate to maintain MLSS above 350 ppm. BOD reduction at this level was only 55 to 65%. When 135 hp/MG was installed to reach the 1,500 to 2,000 ppm MLSS desired, excessive foaming prevented the MLSS from rising above 600 ppm. Sprays and defoamers were found inadequate. Investigations were carried out and chemical substitution was decided on.

The chemical changes made were as follows: 1) Tar Remover SW, an 85% xylene compound, and its carrier, Tanavol, a non-ionic detergent that is a linear ethylene oxide condensate, were replaced with Tanaclean HFP, a high-flash naptha solvent that contains no toluene, and its carrier, Carolid AL, a biphenyl and ester mix; and 2) TSPP, a tetrahexaphosphate chemical, was removed from the scour bath and replaced with a much smaller quantity of soda ash. The latter change was possible because a dry-cleaning unit had been added.

Tables 6-24 and 6-25 show the differences before and after chemical substitution. Table 6-26 shows some COD results on various textile materials. Additional COD information on textile chemicals is needed along with information concerning toxicity.

TABLE 6-24
FOAM-HAMPERED PERFORMANCE DATA

Date	Influent BOD's mg/l	Effluent BOD's mg/l	Removal efficiency, percent	MLSS, mg/l
11/2/72	400	120	70	620
11/9/72	390	130	67	420
11/16/72	340	120	65	520
11/22/72	390	120	69	540
11/29/72	400	130	68	440
12/4/72	369	141	62	420
12/14/72	360	130	64	420
12/22/72	390	130	67	420
12/29/72	380	120	68	400
1/4/73	400	130	68	400
1/11/73	370	110	70	410
1/18/73	380	120	67	410
Average	381	125	67	

TABLE 6-25
CHANGE IN PERFORMANCE WITH FOAM CONTROL

Date	Influent BOD's mg/l	Effluent BOD's, mg/l	Removal efficiency, percent	MLSS, mg/l
2/22/73	370	120	68	440
3/1/73	370	130	65	370
3/8/73	360	130	64	890
3/9/73				1,200
3/14/73	357	70	80	1,280
3/22/73	300	50	83	1,400
3/29/73	329	70	79	1,500
4/5/73	330	75	77	1,670
5/10/73	360	75	79	1,760
6/7/73	340	60	82	2,180
6/13/73	317	52	84	2,299
6/18/73	359	65	82	2,340
6/26/73	362	65	82	2,370
Average	339	65	81	

Source: In-Plant Control of Pollution, Manual 1, EPA 625/3-74-004, Oct. 1974 (4).

TABLE 6-26
RAPID COD RESULTS ON TEXTILE CHEMICALS (39)

Compound	Concentration (mg/l)	COD Rapid Method (mg/l)
Globe Dextrin (glucose)	1200	1167
Dextrose (Baker-glucose)	1200	1130
Fibraloid L-136 (mod. cornstarch)	1100	1147
Covol (PVA)	1000	1585
Sandopan DTC (anionic)	1000	1390
Triton X-100 (nonionic)	400	980
Aerotex Resin 52	1000	435
Cotton (bleached)	1000	1062
Vat Green 1	500	644
Disperse Blue 79	1000	1094
	500	580
	250	330
	150	160
	75	66
Direct Red 81	1000	990
	500	520
	250	215
add 1000 mg/l NaCl	500	592
add 5000 mg/l NaCl	500	707
Mixture 40% disperse dye 40% Covol PVA 20% Triton X-100	(1560 mg/l anicipated COD)	1460

6.4.22 Chemical Substitution Checklist

- Obtain inventory of process chemicals used and BOD_5, COD, and toxicity information on individual chemicals
- Consider substitution of sizes
- Consider substitution of wetting agents
- Consider substitution of carriers
- Consider substituting formic for acetic acid
- Consider use of reactive dyes
- Consider evaluating new resin/catalyst systems

- Consider changing to aqueous print pastes
- Consider alkaline scouring of wool
- Consider use of peroxide or iodate for dichromate oxidation

6.5 Process Changes

This subsection incorporates some of the objectives of the previous subsections. Priority is given to unit operations and process concepts which may reduce waste volume and strength and which possibly could make use of recovered by-products or chemical substitutions. Thought is also given to the majority of readers here who want to learn specifically what changes can be made in the many textile unit processes which can result in savings by increased production, increased efficiency, reduced time, reduced energy requirements, and reduced costs. Consideration is also given to radical thinking in terms of entirely new or emerging technology, since some of this technology will be tomorrow's conservative processing.

The following areas are covered in this subsection:

- Existing process modification
- Comparing similar conventional operations
- New technology
- Emerging technology

There is much fertile area to consider concerning upgrading the unit operations which are currently used to convert raw products to finished materials. This is because in the past little regard has been given to concepts and equipment design dealing with relatively inexpensive resources such as water, certain chemicals, and energy. For example, a very recent ITT mill project indicated that drying the same style 100% polyester on a Marshall-Williams tenter frame consumed around 50% more gas per pound of goods than by use of a Krantz tenter frame (3.4 cu ft/lb. vs. 2.26 cu ft/lb.). This example is used to indicate that the improvements to be made in the years ahead will rely heavily on equipment manufacturers supplied with accurate feedback from textile engineers and chemists. Emphasis is placed on the need for providing feed-back from common problems experienced in production to equipment manufacturers. Also, well-designed projects should be conducted on the mill level and this information quickly channeled to the equipment manufacturer. Participation by trade organization and involvement through conferences is also important. Increased resourcefulness at the individual level and better communication with vendors will be indispensible to accomplishing more efficient production at less cost and with less environmental impact in the near future.

6.5.1 Existing Process Modifications

Several examples of how process modifications have accomplished water and chemical savings are provided next.

Process modification for woven goods preparation in rope form is discussed in the first example (9). The goods in this case could be whites or dyed, and are a polyester/cellulosic blend. Fabric enters from the left at a rate of 225 yds/min. (88 lbs/min.). Initially this range was arranged and counterflowed as seen in Figure 6-31.

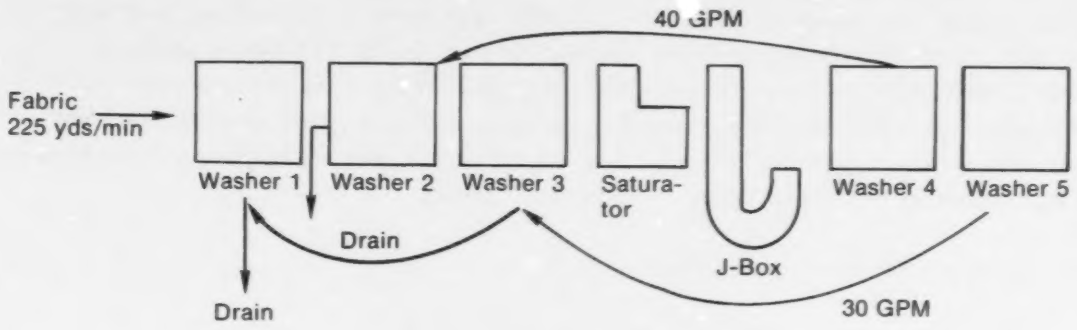


FIGURE 6-31

BLEACHING PROCESS MODIFICATION

After process modification, the major changes were as follows. Washer 1 was eliminated. Flow from Washers 5-3 drain was found to provide adequate washing by reducing from 30 to 20 GPM. Hot water from Washer 4-2 drain was reduced from 40 to 20 GPM. A chemical control monitor was added to meter in constant concentrations of peroxide and silicate. Steam was added to only the middle of three steam chests. Thought is also being given to reducing temperatures from 180 to 170° F, or even to 160° F. There are unquestionably difficult decisions to make when considering process changes in preparation. There may be no better way than to make small incremental changes based on logical thought, then wait for repercussions from dyeing and finishing. If trouble-free production occurs, then further incremental changes, based on logical thought, may be indicated. Surely no one wishes to be responsible for damaged goods, and this is primarily why the present examples are offered. Again, recall that no sophisticated study has been performed in the past dictating the process criteria needed for optimum trouble-free production. Therefore, the necessity created by the energy "crisis," and environmental concerns, may be the motivation required to improve and optimize textile processing as any technology is meant to be.

The second example deals with continuous open-width bleaching of woven polyester/cellulosic goods (9). These goods are run from 55 to 75 yds/min. or 34 to 60 lbs/min. At 1% bleach, such goods can range from 1.3 to 2.2 gal/lb. wash water usage. After process modification, this range was successfully controlled by automatic monitoring of peroxide and silicate. It should be mentioned here that for uniformity to be ensured, chemical should be applied across the width of the saturator. Wash boxes were counterflowed, and temperatures did not exceed 160° F. Consideration was given, after wash box liquor and fabric analysis of residual chemicals, to eliminate possibly one or more wash boxes. The use of vacuum-slot extraction, with water returned to the washer, was found helpful before the dry cans. Staggered slot (off-set) boxes were found preferable over conventional slot boxes, as they allowed the use of greater pressures without pulling of fabric into the slots. This is especially true in cases of lightweight goods running at slower speeds. Figure 6-32 shows a water-line diagram for a rope bleach range.

In the third example, a study involving batch-piece dyeing preparation resulted in better quality goods, more efficient production, and cost savings (48). Unheat-set polyester/rayon containing 4.75% PVA size was prepared continuously by saturation, steaming, high-energy wash, slack loop boil-off, and rinse tank. This resulted in 0.63% residual size which decreased dyeing quality. The initial arrangement used counterflow, but there were no squeeze rolls between stages causing carryover of water and chemicals. Changes included adding nips after the washer and the boil-off, addition of another high-energy washer with nip after the boil-off, and reuse of PVA recovered from the system. Savings totaled $677/day.

A fourth study involving polyester/cotton sateen containing 8.56% PVA starch size consisted of heat setting, enzyme/detergent saturator, steamer, 2 high-energy washers, 2 conventional washers, peroxide saturator, batching dwell, 9 progressive jig boil-offs with rinsing, mercerizing with recuperator, steam washers, conventional washers, and final drying before batch-up (48). Size residual was 0.072%. Changes recommended were nips between high-energy washers, replacement of progressive jigs by a steamer followed by washers with squeeze rolls, the use of counterflow at all units, adjustment of flows in certain washers to concentrate wash liquors, counterflow water in steam washers, and installation of heat reclamation units for the entire range.

The fifth example concerning open-width preparation deals with mercerization (9). This range is run at 80 to 125 yds/min. depending mainly on the finish to be applied. It was found that cloth entering the recuperator contained approximately 4.5% alkalinity on the weight of the fabric. After the recuperator, the concentration of alkalinity was reduced to approximately 0.25%. The value of the recuperator is obvious. Previously, this range contained six wash boxes following the recuperator. After further consideration, other modest process modifications were undertaken, such as elimination of the sixth wash box. Acid for neutralization was added to the third wash box instead of to the fourth, as previously applied. Counterflow of water went from washer 5 to 4 to 3 to 2 to drain. Previously, washer 5 was not included in the counterflow arrangement, and fresh water went directly to the drain. Spray stations before the recuperator were reduced from 7 to 4. Analysis of residual fabric alkalinity after the first washer indicated

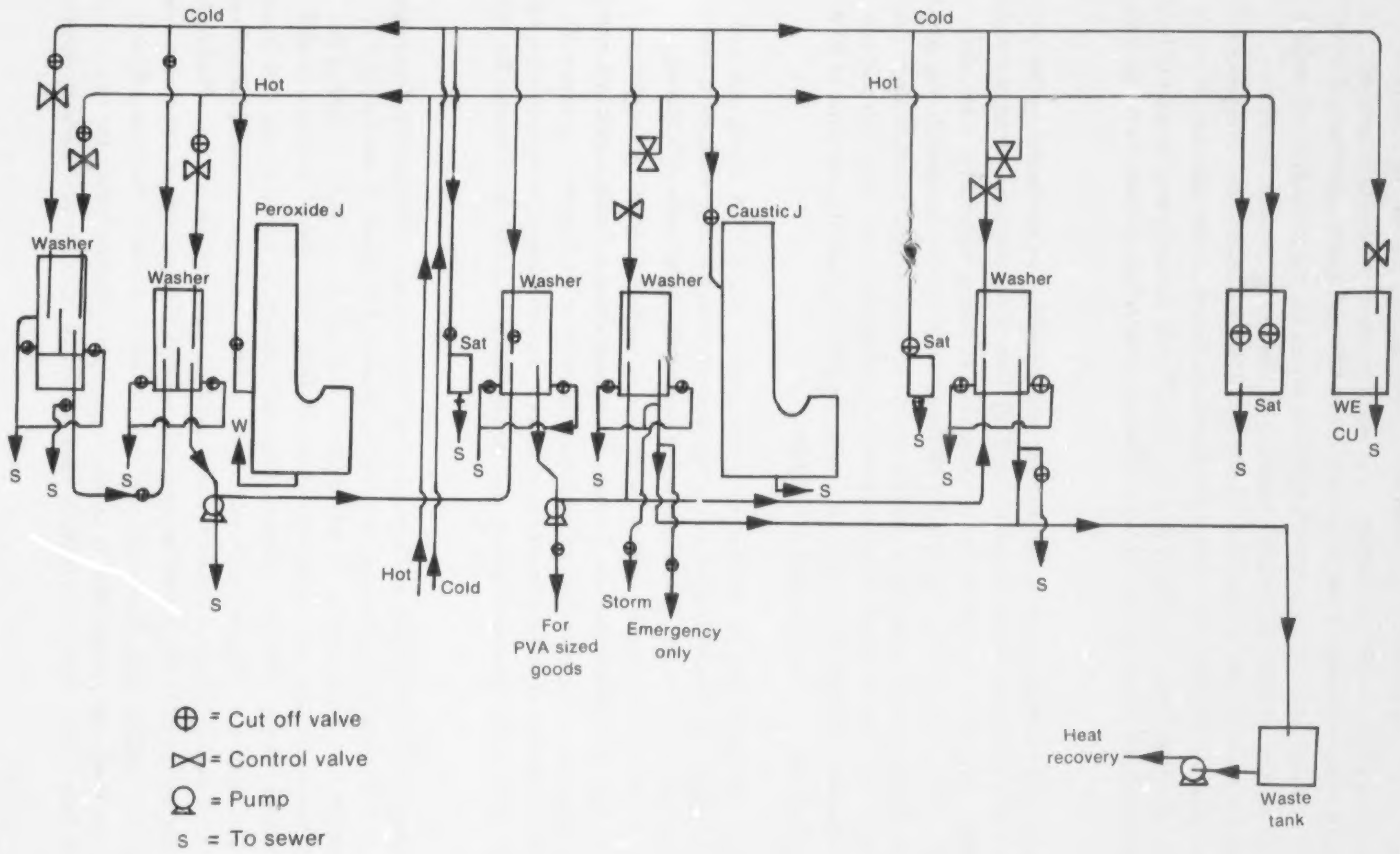

Cold
Hot
Cold
Hot
Washer
Washer
Peroxide J
W
Washer
Sat
Washer
Caustic J
Sat
Washer
Sat
WE
CU
S
Hot
Cold
For
PVA sized
goods
Storm
Emergency
only
Heat
recovery
Waste
tank
⊕ = Cut off valve
⋈ = Control valve
Ω = Pump
S = To sewer

FIGURE 6-32

BLEACH RANGE WATER LINES

residual alkalinity was reduced to 0.05% (owf). Such findings strongly suggest reassessment of the practice of acid neutralization and what might be excessive washing at too high temperatures. Current practice indicates temperatures over 180° F (approaching 200° F) in three of the remaining five wash boxes. Study has indicated temperatures closer to 160° F may be all that is actually necessary under these production conditions. Water usage in this mercerizing range generally averages about 1 gal/lb. In summary, possibilities for water reduction and heat savings have been indicated in the mercerizing range by simple process modification.

The final example of good preparation practices shows specifically how a mercerizing range might be piped for counterflow and reuse in Figure 6-33 (9).

6.5.2 Dyeing Process Modification

Preparation has been given exceptional attention in this discussion. This is because most plants feel that good preparation may be more critical than what follows. However, there are those who would advocate that thinking back from the finished product is the better approach. Be that as it may, at this stage in the assessment of plant operations, the potential for process modification appears great enough to allow both schools of thought to prevail profitably.

This example describes suggested procedures which could be profitably incorporated into disperse dyeing on a thermosol range (9). Various styles should be grouped by weight. The lighter weight goods would run at a faster speed through the equipment, requiring less energy (less predrying), and may, or may not, profit from the use of vacuum slot extraction before final drying cans. It has been discussed that off-set vacuum slots may best be applied to light weight goods. Suction water should also be re-entered into the wash boxes for reuse. Total hot water flow in a disperse dye system would be greater than most other dyeings, such as disperse/reactives, disperse/sulfur, disperse/vat, reactives only, sulfur only, or vat only. Vats and disperse/vats would probably require half the total hot wash water flow than disperse dyeing alone. It seems doubtful that thermosol dye washing would require water higher than 170° F. Exceptions might be side/center/side shading, poor appearance, and when a particularly good after wash is required. A band meter should set cloth final moisture after drying to process conditions to prevent overdrying when possible. It can also be repeated that iodate, peroxide, or laking agent oxidation may be used to replace dichromate.

Considerable attention has been given to continuous operation, and at this point comment is made on beck dyeing. It has been suggested in earlier subsections that although long holds may be necessary for heavy shades to exhaust, light shades will exhaust much more rapidly. Holds possibly no longer than 20 minutes should be investigated (9). Temperatures should be considered carefully. Perhaps, temperatures of 250° F could be cut back to 240° F. Temperatures running at 240° F may be cut back to 230° F.

It has also been suggested that running rinses may be profitably replaced by fill and drop washing. Russell (ICI) has suggested two fill and drops heated to 200° F will often accomplish as much

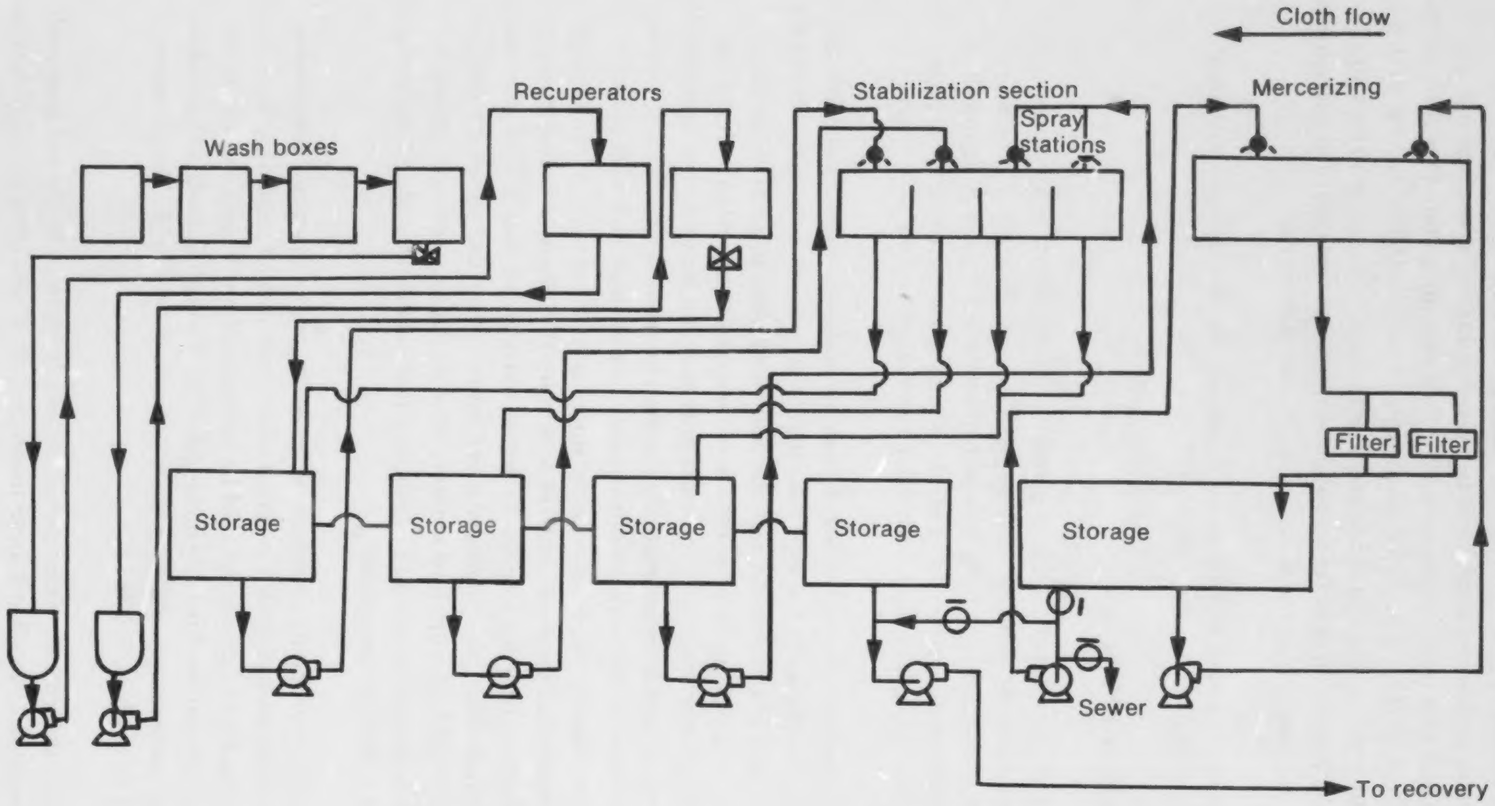

Cloth flow
Recuperators
Wash boxes
Stabilization section
Spray stations
Mercerizing
Storage
Storage
Storage
Storage
Storage
Filter
Filter
Sewer
To recovery

FIGURE 6-33

MERCERIZING RANGE PIPING

as an hour of running wash at 160° F (13). The virtues of this suggestion should be considered where appropriate. The reuse of cooling and steam condensate water has been discussed in subsection 6.2.

For the optimal utilization of water and chemicals during processing of textured polyester wovens, the following factors should be taken into consideration (49). If pre-heat setting can be avoided, it is desirable since pre-heat setting can decrease dye yield, reduce stretch, and make scouring more difficult. A key-step in producing optimal results with minimal water usage and reworks may be warp and filling tensionless open-width boil-off. Equipment such as washers from Brich Bros., Fleissner Suction, Jawetex rotating jet, Mezzera, and the Nizzen Sofcer are proven toward this end. The latter machine utilizes a net conveyor to induce relaxation and spray jets for scouring. Non-ionic detergents and mild alkali around 208° F might best be used. Scouring and dyeing in one bath, although seemingly more economical in resources and total cost, can lead to problems of nonuniform dyeings due to insufficiently clean fabric. Carriers often preferred in dyeing are o-phenyl phenol or biphenyl for atmospheric dyeing, butyl benzoate or modified aromatic solvent types in pressure becks, and special low-foaming carriers for jet dyeing. At this time, it is still controversial whether pre-heat setting improves barre' or filling bands. Optimal finishing steps to consider include moisture extraction to 25 to 30% moisture, relaxed loop drying at 250 to 275° F to minimize puckering, and heat setting to maximize overfeed on a pin tenter at 340 to 370° F for 20 to 30 seconds.

6.5.2.1 Resin Finishing

In resin finishing, Newport Finishing Corp., Fall River, Mass., reported very favorable experience with hot catalyst mixtures using glyoxal resins, i.e., magnesium chlorine/aluminum salts or metal salts/φ-hydroxycarboxylic acid (39). These systems were said to cure at lower temperatures and save energy. It is essential to precheck additive compatibility with the hot catalyst, particularly softeners, brighteners, and hand builders.

Clean-up wastage was improved in a resin usage scheme reported by Towne (Fiber Ind.) (37). Clean-up went to the drain after each use of the make-up tank, the supply tank, and the use tank. Pumping, piping, and automatic closing valves were installed providing return lines from the use tank to the supply tank, and from the supply tank to the make-up tank. This procedure reduced wastage during clean-up and prevented wastage during shut-down periods.

6.5.2.2 Compatible Process Sequencing

Mill experiences indicate that considerable potential often is seen to exist for better flow of processing (9). For example, in wool processing, sequence of acid fulling-alkaline bleach-acid dyeing was observed to be poor from a water-use standpoint because lengthy rinses were required between processes. This is because residual acidity from fulling would tend to neutralize (waste) the alkaline bleach if not rinsed adequately. Furthermore, alkaline fabric after bleaching could interfere with acid dyeing if not properly rinsed. Thought should be given to the possibility of slightly acid bleaching which can provide perfectly adequate bleaching and considerably less water and perhaps less chemical usage.

6.5.2.3 Improved Sizing, Slashing and Weaving

Various aspects of sizing have been considered in other subsections. This includes size reclamation; use of prehydrolyzed sizes which provide better penetration, better film forming properties, and better biodegradability; and solvent size application and recovery. This discussion now considers the topic in somewhat wider perspective, i.e., size formulation, slashing, weaving, desizing, and finishing plant performance.

In opening, comment should first be made about claims of new, improved warp sizes which occur so frequently and without sufficient evidence, that most mills are loath to consider change. Olson (National Starch) has given a concise state-of-the-art summary at this point (50). Trends indicate that PVA will be increasingly used in the future, cost being a major deterent in its more wide-spread use currently.

Some theoretical discussion of the ideal is warranted here. If a yarn requires 7% PVA sizing, Olson suggests 4% provides the weight and bulk needed to absorb the strains and blows of the loom. This he calls the threshold size percentage. The other 3% provides the required adhesion and abrasion resistance. Starch, which has functionality of its own, could provide the 4% "filler," and lower costs, while PVA provides the film-strength it is best suited for. Unfortunately, compatibility has not yet been accomplished, although substantial progress towards this goal has been indicated. From cost/performance and pollution standpoints, it must be said that this route could appear most beneficial for some in the future. The reasoning behind this suggested approach begins with formulation benefits. A proper mixture of compatible modified starch/PVA should possess the proper viscosity for minimum application and penetration. The film forming properties should then be adequate for good weaving performance. Then relatively easy removability (minimal desizing requirements) should also be accomplished. Obviously, with this accomplished, the PVA/starch desize could optimize the task of degradability by conventional biological treatment. There is neither too great a BOD_5 load as with starch alone, nor too great a COD problem as with PVA alone.

The potential benefits of such an approach include:

- Use of less size
- Satisfactory weaving
- Less chemical, heat, and water used
- Better treatability
- Less overall cost

6.5.2.4 Solvent Processing

After approximately 15 years of serious study involving solvent processing, the AATCC gathered a symposium in Atlanta during January 1973 to discuss the state of the art. This landmark meeting focused attention on the capabilities and problems of solvent processing. It was an invigorating forum where mill men spoke freely of their likes and dislikes, and chemical and equipment manufacturers went back to the drawing boards for more work. After the meeting was completed, it became clear that the idea of solvent processing gaining acceptance merely to provide relief from environmental problems was untenable. Solvent processing will be introduced and accepted in general only when superior results in processing and product are demonstrated at economical costs.

Some of the major lessons learned as a result of the Atlanta symposium were:

- Suitable machines can be manufactured and operated so as to control air pollution in the work space.
- Solvent loss can be expected to be an economic problem, and tight control is needed to keep solvent loss per operation below 5% of fabric weight.
- There is no immediate widespread commercial use of solvent finishing expected for woven goods.
- A firm position has been established for solvent scouring and finishing of synthetic knit fabrics. The primary reasons are that it is beneficial to fabric quality to avoid wetting with water and some finishes (silicones) can only be used in solvents.

Solvent scouring of woven fabrics has not indicated that the properties of solvent scoured fabrics are generally superior to aqueous methods. This is despite intense efforts towards this goal. Many functional finishes have been demonstrated to be applied from solvents. It has been suggested that the advantages of the properties shown so far have been insufficient to justify a change-over from the more familiar aqueous systems. In speciality cases, the applications of stain and soil resistant finishes to upholstery fabrics and drapery materials have become fairly standard procedures.

Synthetics' Finishing (Hickory, N.C.) pioneered the application of stain repellents via solvents in 1960 (51). After engineering modifications, the system was capable of reclaiming 95% of the solvent for reuse in 1969. Approximately 3000 lbs. of activated carbon adsorbed 400-500 lbs. of trichloroethylene in this plant. Two adsorption columns were used, one adsorbing vapor while the other discharged. Control was automatic. Steam was used to discharge the adsorbed solvent. After saturation and a build-up of 3 psi, the steam picked up the solvent as a vapor. The steam-solvent mixture proceeded to a condenser that cooled the mix, which then dropped into a decanter. Separation was quick, and the bottom solvent layer was drawn off for reuse. Water was discharged to the drain.

Synthetics' Finishing also applied Scotchgard or Zepel stain repellents and a stabilizer to high-grade woolen apparel fabric. Both chemicals were sprayed in one bath by staggered spray nozzles. The spray cabinet was also saturated with solvent-chemical vapor. Runoff was collected and recirculated. From the spray cabinet, goods moved into the steam-heated drying chamber where the plant circulated about 3,500 CFM of air at 200° F. It then was led to the solvent recovery system.

Synthetics also applied latex backing to automobile and furniture upholstery. Knitted and woven fabrics were treated on a plant-designed range which could back fabrics by spray, roller coating, knife coating, or transfer-kiss methods. In addition to the various methods of applying latex backings, electric heating units (Calrod) were used in the drying section. Drying essentially only removed moisture from the coating applied. The heated air was applied from top, bottom and halfway from each end. Four sections with damper control of each section added to the equipment flexibility. A moisture indicator was used to adjust speed by varying motor speed.

Certainly, this example indicates that on technical grounds solvent processing can offer an attractive solution to some problems. However, it should be pointed out that new problems associated with air pollution may arise in the future. It has been mentioned that tight control over solvent systems is required to keep solvent losses below 5% of the fabric weight. Porter reported in 1972 that nearly one ton of solvent per day per range might reach the atmosphere (52).

Raymond Allen reported that processing of fancy or yarn-dyed goods was attractive for solvent processing and recovery (4). This is because aqueous methods generally appear better suited for oil-based lubricant removal before dyeing. The use of solvent versus aqueous methods has demonstrated a total plant water requirement reduction from 20 to 5 gallons per pound. It was pointed out that such comparisons were made between different plants rather than actual reductions in one plant.

Allen suggests that the most reasonable approach for a plant deciding to employ solvent processing is to buy both solvent processing and solvent recovery systems from one supplier. Such an approach is usually most economical from a capital cost and installation standpoint, and it also would tend to help ensure successful operation while providing easier maintenance and repair. Also, consideration should be given to fixed detection units located at the entry and exit ends of the production equipment and near the recovery unit. A portable unit should be on hand and any area indicated to be susceptible to leaks should also be considered for a fixed detector. OSHA regulations provide for concentration limits of solvent in the operating area, and equipment should be thoroughly examined before purchase.

There have been examples of problems strongly felt associated with solvent vapors in the plant. Drawing of solvent-laden air to dryers or tenter frames may result in the conversion to hydrochloric acid gas (9). Fabric weakening, browning of cellulose, or dye degradation are some of the possible difficulties which should be anticipated. Allen estimates the critical concentration of perchloroethylene to cause such problems to be in the range of 200 to 500 ppm (4).

Actual problems experienced by a plant reported by Allen in the installation, startup and operation of a solvent dry-cleaning process with solvent recovery are summarized as follows:

- Solvent consumption during start-up ranged from 20 to 30%. After fine-tuning consumption decreased to 5 to 8%. It was felt that manufacturer's claims of 3% solvent consumption would be extremely difficult to attain.

- Factors contributing to solvent consumption were mainly machinery vibration causing leakage, poor fitting couplings and hose problems, poor door seals, recovery unit malfunctions, and squeeze-roll deterioration. Tweksbury suggested that if the 950 million pounds of knit polyester and nylon finished in 1972 were solvent scoured, with a recovery rate of 99%, nearly 10 million pounds of solvent could be released to atmosphere (4).

On the other hand, John Steward (Northern Textile Assoc.), acting as mill liaison, reported that a solvent system used on wool-nylon-cotton fabrics cut water consumption in a mill from 150,000 to 10,000 GPD (53). It was added that reductions in chemical consumption, labor costs and time spent were also achieved. A 92% BOD_5 reduction was reported in terms of lbs./1,000 lbs. goods. But in concentration units (mg/1), higher values were said to occur. In this completely sealed system, solvent was said not to be lost to the atmosphere. However, 10 gallons per day of 1, 1, 1-trichloroethane solvent were lost from the 1,200 gallon capacity unit.

Solvent preparation has been vigorously investigated by the Shirley Institute and ICI Scientists since the late 1950's. The basic steps in the process development by ICI proceeded essentially as follows. Hydrocarbon solvents were found to wet out fabric rapidly. A fabric's oils, fats and waxes were dissolved in a very short time. Solvent soluble surfactants were found to simplify removal of the oils, fats and waxes. Enzymes were found that were suitable for suspension in solvent. Adequate desizing was demonstrated. Partial bleaching was demonstrated in the Markal III process. It should be stated that in at least one U.S. plant, the early generation ICI desize equipment was shown to be inefficient and was not used in production (9).

The newest Markal "B" pilot process (scour/desize/bleach) eliminates the wash-off between steaming and bleach pad. Furthermore, the water seal after steaming is modified to serve as seal and pad applicator also. Eliminating the separate pad application and wash-off saves floor space and capital expenditure. Figure 6-34 shows an example of an envisaged Markal B minute range (34). A pressure bleach can replace the "steam" unit if desired.

As it stands now the Markal ranges have no significant economic advantage over conventional aqueous methods in range cost, total processing costs per pound, labor, steam, water or electricity. The Markal B range may cut costs in range costs, total processing, steam, water and electricity.

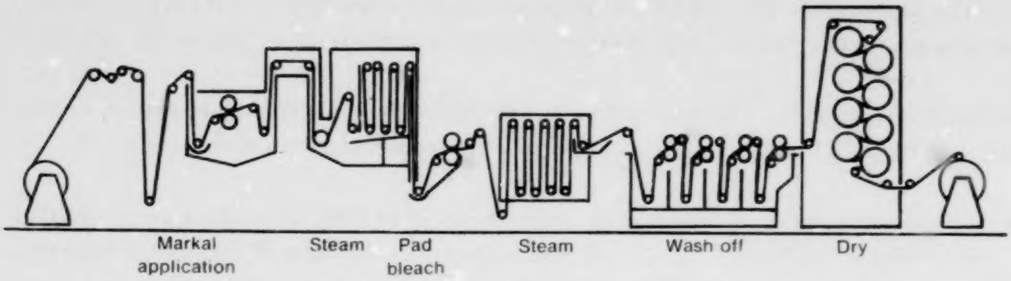


FIGURE 6-34

MARKAL B ('Minute Bleach') RANGE

Confirmation must await the installation and operation of a successful commercial Markal machine. Dow has reported development work on a process to recover and recycle size material in a solvent system (34). Increased equipment costs associated with size recovery can be off-set by reuse of the size chemical, it is said. The primary problem appears to be development of a new size which can be recovered and reused. Another problem would be the logistics of such an operation. Conventionally, desizing is performed at the finishing plant, and greige mills would face, in general, a radical departure from traditional procedures of processing. Another problem is related to the rapid wetting out of fabric by solvents. This has tended to allow too much penetration of size into the yarn bundle and too little peripheral coating. Higher viscosity sizes would produce problems later in solvent and size recovery. However, the potential advantages of solvent sizing and desizing are also impressive. These include: better weaving performance, size recycle, possible improved dyeability, decreased floor space, decreased utility and manpower requirements, and humidity insensitivity. This has not mentioned that less water usage would also occur, and no size would need treating. Certainly, the promise of solvent sizing and desizing is great. However, since the 1973 Atlanta Solvent Symposium, no successful commercial application has been reported. Reluctance on the part of textile management to encourage or accept the innovation has been mentioned as a deterrent to vigorous developmental efforts. It can be said that the technical difficulties with this concept have off-set strong motivational textile interests at this time. Figures 6-35 and 6-36 indicate the Dow Solvent slasher and desize concepts.

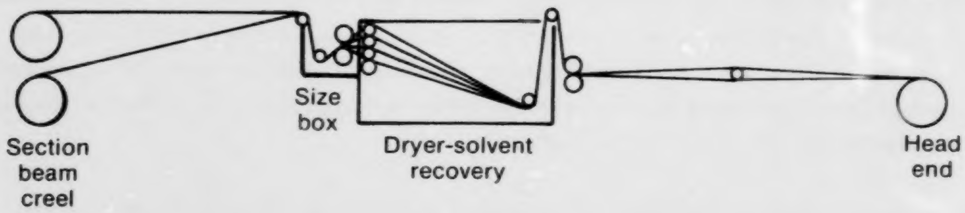


FIGURE 6-35

DOW PILOT SOLVENT SLASHER

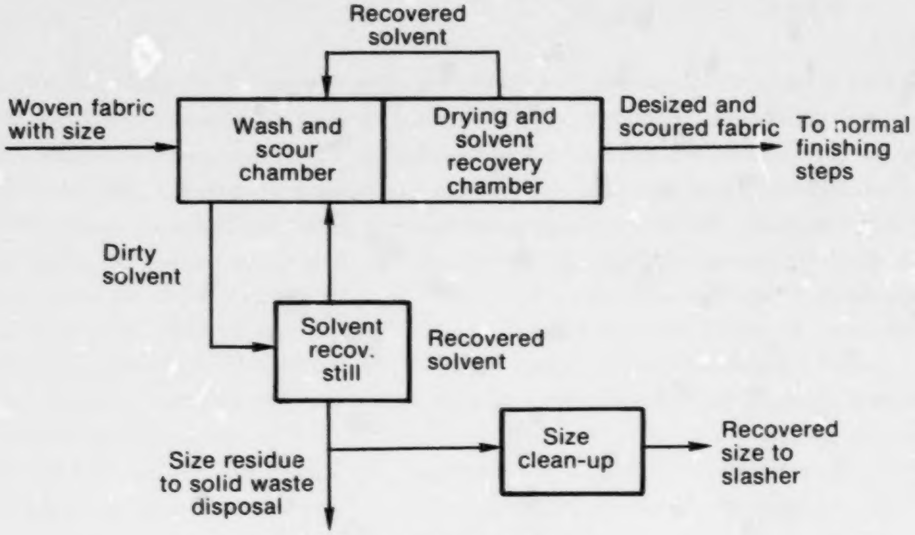

Recovered solvent
Woven fabric with size
Wash and scour chamber
Drying and solvent recovery chamber
Desized and scoured fabric
To normal finishing steps
Dirty solvent
Solvent recov. still
Recovered solvent
Size residue to solid waste disposal
Size clean-up
Recovered size to slasher

FIGURE 6-36

DOW SOLVENT DESIZE PROCESS

Commerical solvent scouring equipment vendors today claim that 10 to 12 oz. polyester can be scoured from 4 to 6% oil to around 0.2 to 0.4% residual at speeds between 25 to 35 yds/min. Perchloroethylene losses are said to be around 2.5 lbs. per 100 lbs. of goods. Furthermore, vendors are continually modifying current equipment. For example, one vendor has replaced nips with suction slots to eliminate roll break down problems. It is also emphasized that to maintain high efficiency, maintenance and seal replacement need to be carried out on a regular basis (whether or not the seal has failed). An equipment schematic by Bruckner is shown in Figure 6-37.

Oil residues resulting from the cleaning operation may be preferably burned. Some companies specialize in this field and collect the residues.

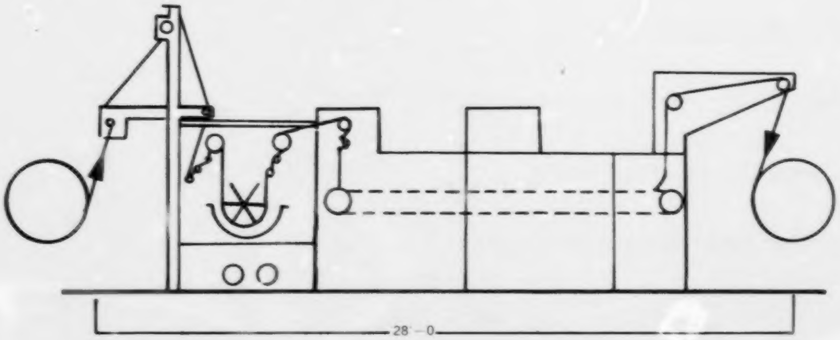


FIGURE 6-37

BRUCKNER CONTINUOUS SOLVENT SCOURING MACHINE
FOR KNIT GOODS — TYPE: SOLVENT

6.5.2.5 Solvent Dyeing

Solvent dyeing has received most of its criticism regarding the lack of adequate dyestuff (54). However, in proper order, the solvent should first be commented on. Briefly, a solvent to be suitable for dyeing must be a solvent for the dye, must be a swelling agent for the fiber, must be safely containable at dyeing conditions, and it must be easily recoverable. In fact, there is not such material available. Therefore, compromise has been necessary. The most significant successes in the development of solvent dyeing systems have been in the conversion of existing dyes into forms compatible with selected solvents. Ciba-Geigy and Allied Chemical in conjunction with Dow Chemical have been the most vigorous advocates of solvent dyeing systems. Allied reports formulations and procedures for use in the Burlington Engineering laboratory beam dyeing unit (55) (56). In the same reference, and in the Atlanta Symposium, a continuous procedure using superheated vapor fixation was described (54). It can be said that limited solvent dyeing systems have been shown to be technically feasible on a pilot scale basis. However, of the hundreds of European and American patents issued, most have been assigned to dye manufacturers. Since the features of most patents will be practiced by the dyer, rather than the dye manufacturer, most probably the successful commercial venture, should it appear, will be a combination of several contributors (57). Judging from the lack of enthusiam on industry's part, this innovation is difficult to envision soon. At this point it appears that someone will have to demonstrate clearly the economic advantage of solvent dyeing over existing procedures, before commercial acceptability on any size scale becomes a general reality. Once the economic feasibility is established, then perhaps some of the promises of solvent dyeing may be realized. These advantages may include:

- Elimination of a pre-scour
- Smaller, less costly equipment
- Flexibility of making short, continuous runs
- Low utility requirements
- Considerable water usage reductions
- Better-leveling and uniformity
- Better reproducibility between runs
- Possibility of integrated dyeing and finishing

The schematic in Figure 6-38 shows the dye padder and superheated perchloroethylene fixation unit for continuous processing as used by Ciba-Geigy and Allied Chemical (54).

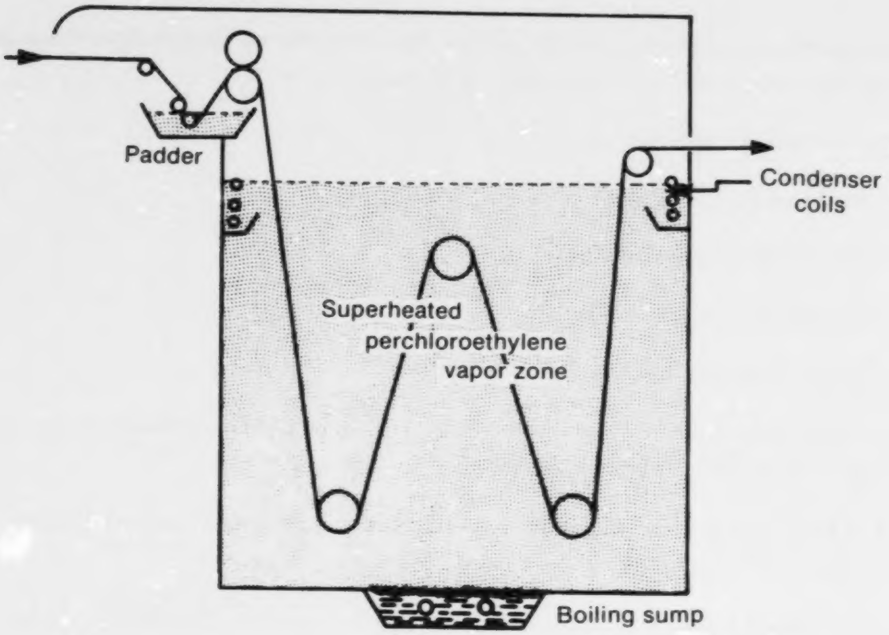


FIGURE 6-38

SCHEMATIC DIAGRAM
SUPERHEATED PERCHLOROETHYLENE FIXATION UNIT

During the 1973 AATCC Solvent Symposium in Atlanta, Gaston County defined its responsibility as equipment manufacturers to industry. "Most textile mills expect practical assessments of processes from their suppliers. We, as equipment suppliers, cannot take the responsibility of solving the water and air pollution problems of the mills, but we have a duty to help them in the attainment of set standards such that, overall, reasonable profits can still be assured."

Gaston County contended also that economy is the only criterion of importance if the quality of processing is not affected. Assuming that the quality of goods is the same when solvent procedures are compared to conventional procedures, the following list gives some key factors which should be considered in an economic evaluation:

- Look at your total operation from receiving to shipping, including costs to assure compliance with air and water pollution standards.
- The type of people in your plant.
- Do you need new equipment or can the existing equipment be converted?
- Can you afford to have adequate waste treatment facilities and still have solvent

reclamation systems or would the installation of solvent equipment lighten the load on your wastewater treatment plant significantly?

- Your water and utility costs.
- Your location.
- Solvent costs and availability.
- Dyestuffs and chemical costs.
- Can you maintain the necessary flexibility?
- In what time frame do you have to work? You may not have a choice, except to update your water treatment plant.
- Examine your present operation carefully. It is quite possible that you do not utilize your water and utilities in the most efficient manner.
- Labor market, automation, material handling, etc., are still often points of consideration.

6.5.2.6 Remaflam Machine – Artos

In the 1973 Atlanta Solvent Technology Up-Date, Farbwerke Hoechst AG described a venture with Artos for a rather spectacular piece of equipment. In this process, polyester dyestuffs are dissolved in methyl alcohol and the fabric is padded in the solution. The fabric is then ignited and the methyl alcohol burns off as the fabric passes along at 130 to 140 ft/min. Dyeing takes place at this point and the equipment is intended to replace the Thermosol process. Balmforth reported 10 months later (ATME-1-1973, Greenville) that the Artos machine (Remaflam) was not on display but is apparently soon to be available for dyeing polyester (9). This process is cited as middle of the road between aqueous and solvent dyeing.

6.5.2.7 STX Solvent Dyeing

STX (Paris, France) offers a solvent dyeing process which uses methanol and perchloroethylene (1:10 ratio). During dyeing, the methanol is slowly distilled off (and recovered) causing the dissolved dye to become less soluble. This state causes the dye to exhaust into beamed fabric. STX says polyester, silk, wool and nylon have been dyed by this process with 100% dye exhaustion. This is said to eliminate pollution from dyebath's dumps. STX claims dyeing is faster and at lower cost because nearly pure methanol and perchloroethylene can be recycled as is. Very little information is available on commercial application of this equipment. Contrary to STX claims, it is reasonable to assume that fiber extractables and conventional dyestuff ingredients (salts, oils, diluents, dispersants, etc.) will eventually build up.

Operational sequences are shown in Figure 6-39.

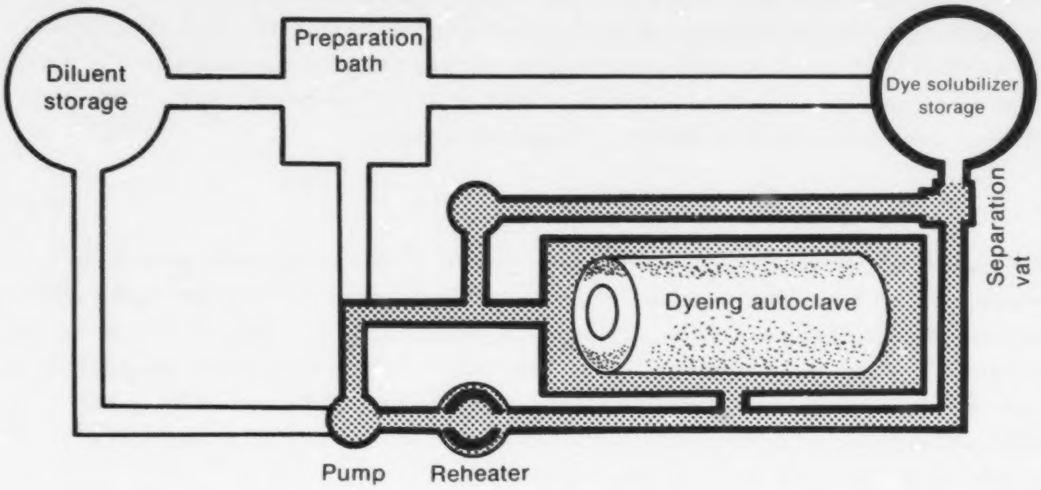

Diluent storage
Preparation bath
Dye solubilizer storage
Separation vat
Dyeing autoclave
Pump
Reheater

FIGURE 6-39

STX SOLVENT DYEING PROCESS
(Dyeing until total exhaustion by progressive separation of the dye solubilizer.)

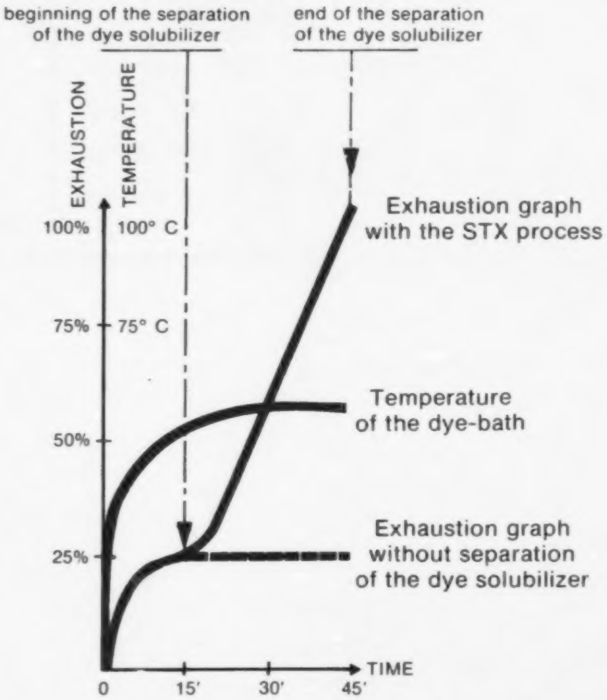


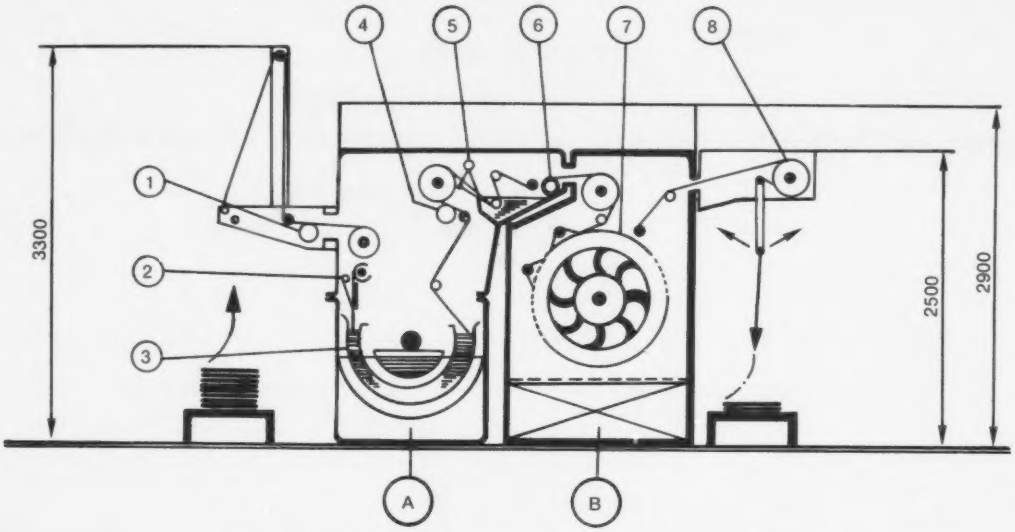
FIGURE 6-40

STX EXHAUSTION GRAPH

The dye-bath exhaustion graph shown in Figure 6-40 provides an illustration of the STX process. Exhaustion without separation of the dye solubilizer (methanol) may reach 20 to 70%. This would depend on the dyes and operational conditions. Progressive separation of the dye solubilizer makes a controlled and complete exhaustion of the bath possible at the end of the operation with dyes insoluble in the diluant (perchlorethylene).

6.5.2.8 Duobond Corporation

An August 1974 report told of an invested $200,000 for a continuous solvent scour range manufactured by Rimar (Italy) and sold in the U.S. by ITM Ltd. (58). The range replaces three batch machines and the company expects pay back within two years. Called the Vibro scour, it operates at 25 yds/min. (manufacturer claims 35 yds/min.). Polyester doubleknit and polyester/acrylic blends are processed in weight from 5 to 16 oz/yd. Oil content reaches 7% in, and residuals range from 0.2 to 0.5% out. The distillation unit recovers solvent around 600 GPH. A schematic and technical data follows in Figure 6-41.



TECHNICAL DATA

Skeleton drum width	2.3 m.
Width of material, up to	2.2 m.
Speed of work	5-25 m./min.
Absorbed power	20 KW
Voltage	to be stated
Frequency	50 Hz
Saturated vapor	4-6 Atm.
Consumption of vapor	300-600 kg.
Water not more than 20° C.	1.5-6 Atm.
Water consumption not polluted and totally recoverable at a temperature of 40-45° C.	5-10 Cu.m.
Compressed air	5-6 Atm.
Consumption of air	700 l/hr.
Consumption of solvent (on weight of material)	5%
Residual grease (within 5%)	0.5%
Output (average per hour)	500 kg.

LEGEND

A = Scourer
B = Dryer
1 = Inlet of deodorizer
2 = Pre-scour spray tube
3 = Vibro Scour patented scouring device
4 = First aspiration tube
5 = Spray head for rinse
6 = Second aspiration tube
7 = Drying drum
8 = Outlet, deodorizing cylinder and material

FIGURE 6-41

DUOBOND CONTINUOUS SOLVENT SCOUR RANGE

6.5.2.9 Aqueous Scouring of Knits

Early in 1970, Jeffries Southern Processors, Albemarle, N.C., used conventional open-width washers to scour circular doubleknits and tricots (59). Oil contents from 6% were reduced to residuals of around 1½%. In addition to the poor scouring performance, the open-width washers stretched the fabric about 3%. With modifications to a conventional aqueous washer, Jeffries reduced residual oil down to 0.01% with a 10% bulking efficiency while operating at 22 to 35 yds/min. The bulked fabric capability, it is said, is nearly able to eliminate redyes, saving water consumption, chemicals and overall cost. The first stage of the system is a dwell in a J-scray, fed with 140° F scouring liquor. Fabric leaving the J-scray goes over scroll rolls directly onto a tensionless stainless steel conveyor screen. At this point, jet scouring sprays spray water circulated at a rate of 500 GPM at about 40 psi. The fabric then enters the bulking tank where it receives mechanical agitation between 160 to 200° F, depending on the fabric type and the bulk required. Tighter constructions usually require higher temperatures. After bulking, a series of spray pipes alternates with air knives to rinse the fabric, and a vacuum extractor at the exit end helps to recirculate and counterflow water (Figure 6-42).

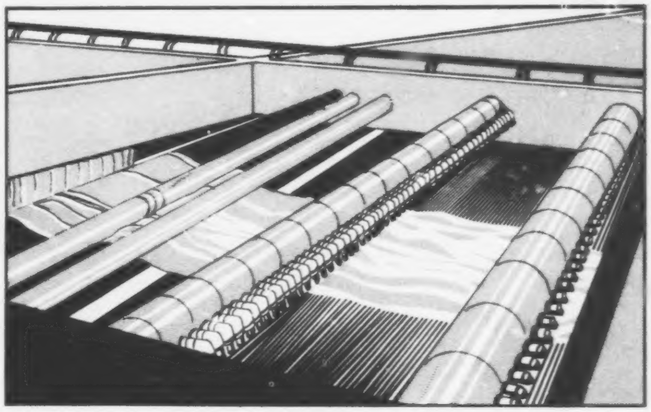


FIGURE 6-42

JEFFRIES AQUEOUS SCOURING OF KNITS

6.5.2.10 Aqueous Knit Washer – Birch

Balmforth (I.T.T.) reported in 1973 on a Birch Bro. aqueous knit washer exhibited in Greenville (ATME-1-73). This equipment consisted of three box washers through which the goods are conveyed on a mesh screen at around 30 yds/min. Vacuum extraction was used after the last two boxes. Other manufacturers were seen exhibiting very similar equipment. Birch feels aqueous scouring is cheaper than solvent processing, gives better bulking and better hand to the fabric. Running costs were said to be approximately half that of a continuous solvent range. Capital cost of this range was quoted at $75,000.

6.5.2.11 Liquid Ammonia Technology

In 1973 liquid ammonia processing was hailed as the biggest scoop of recent years (60). However, due to the scarcities in natural gas feedstock, used in liquid ammonia production, costs have more than tripled.

Before costs skyrocketed, liquid ammonia had potential reuse, or could be removed by a roof burner breaking the ammonia down to nitrogen and hydrogen, it held the edge on solvent dyeing (because it could handle water soluble dyes), and appeared utilizable in conventional equipment. Economic and pollution advantages were obvious. Liquid ammonia dyeing was loosely said to fall into the category of dry dyeing.

Briefly, on cellulose, liquid ammonia rapidly penetrates native cellulose forming a complex and resulting in the cleavage of hydrogen bonds (61). This is accomplished by swelling and plasticizing effects. If the ammonia is removed by evaporation, cellulose III is found to predominate. If the ammonia is displaced by water or alcohol, cellulose I predominates.

6.5.2.12 Mercerization

See subsection 6-4 for discussion.

6.5.2.13 Dyeing

Exceptionally rapid dyeing has been claimed using direct, disperse, reactive, naphthol and sulfur dyes from liquid ammonia dye baths. Arthur D. Little patented the idea of continuous dyeing with liquid ammonia. Seth Kane (Kane Inds., Gastonia, N.C.) produced commerical equipment reported in 1973 called the Rapid Annydrous Method (RAM) shown in Figure 6-43 (62).

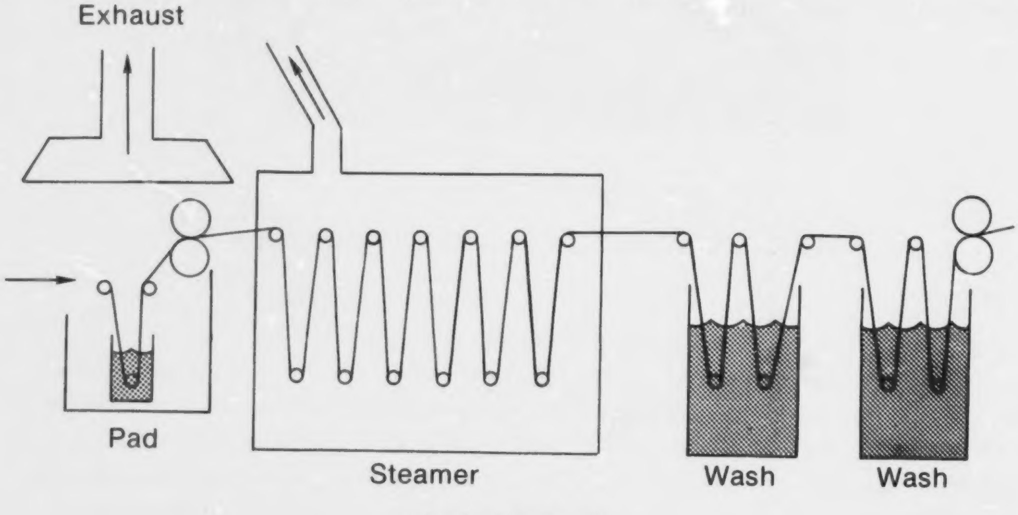


FIGURE 6-43

FLOW DIAGRAM OF THE RAM DYEING SYSTEM SHOWING THE EQUIPMENT NEEDED

In this system all fibers but acetate and wool are said to work. About 95% of available dyestuffs are said to be compatible. Speeds up to 120 yds/min. have been obtained because ammonia "wet-out" is nearly instantaneous. Speed was limited by steaming times of 3 to 30 seconds depending on fiber and construction. Here the fabric is padded with dye dissolved in anhydrous ammonia at–40° F. Steam then flashes off ammonia and sets the color. An afterwash rinses off excess dyestuff. Exhausted ammonia is usually scrubbed with acid and sent to the atmosphere. Advantages include less water used and less chemicals (no carriers, surfactants, penetrants, salt or sequestrants).

6.5.2.14 DP Finishing

J. P. Stevens' investigators indicated that liquid ammonia pretreatment and the removal of ammonia by air drying prior to the application of resin from aqueous solution or emulsion resulted in permanent press cotton with improved over-all performance, especially when the curing consists of short steaming and subsequent dry heating (see subsection 6.4 for discussion) (41).

6.5.2.15 Flame Retardant Finishing

The use of anhydrous ammonia after applying flame retardant to cotton with the THPOH/NH_3 procedure has been reported mainly by the British, SRRL and Hooker Chemical Corporation. Both liquid and gaseous ammonia have been used in such procedures, J.P. Stevens reported in 1974 that where aftertreating has little effect on the physical properties of fabric, pretreatment followed by exchange of ammonia with water improved fabric performance (41). Specifically, the workers reported that when treatment before the FR finish is applied, it modifies the cellulose so that no significant fabric stiffening occurs. Flame resistance is still adequate. The effectiveness of PE/cotton blends was less pronounced.

It is difficult at this point to envision exactly what processes will be created around liquid ammonia. Indications are that new fabric properties are created which will take time to explore and evaluate. If new feedstocks are found and/or costs again become economical, it is reasonable to assume the same interests as shown in 1973 may be rekindled.

At this time the Sanforized Co. has acquired the original Norwegian patent and with Burlington's Erwin Mills has a full-scale operation (46). Termed the Sanfor-Set process by the Sanforized Co., liquid ammonia will treat jean materials, such as denim, and follow it by compressive shrinkage to yield a wrinkle-free soft fabric. The process is said to be continuous, non-polluting and affords a 90 to 95% recovery of the ammonia. Briefly the process, as shown in Figure 6-44 consists of pre-drying to remove moisture, followed by entry into a sealed chamber which is kept at a negative pressure to prevent ammonia fumes from escaping. The fabric then passes through a bath of liquid ammonia (bp-28° F). After squeezing, it is given sufficient reaction time before passing over two Palmer blanketed drying cylinders where the fabric width is controlled to the desired dimension. At this time the ammonia is driven off and collected in a recovery unit.

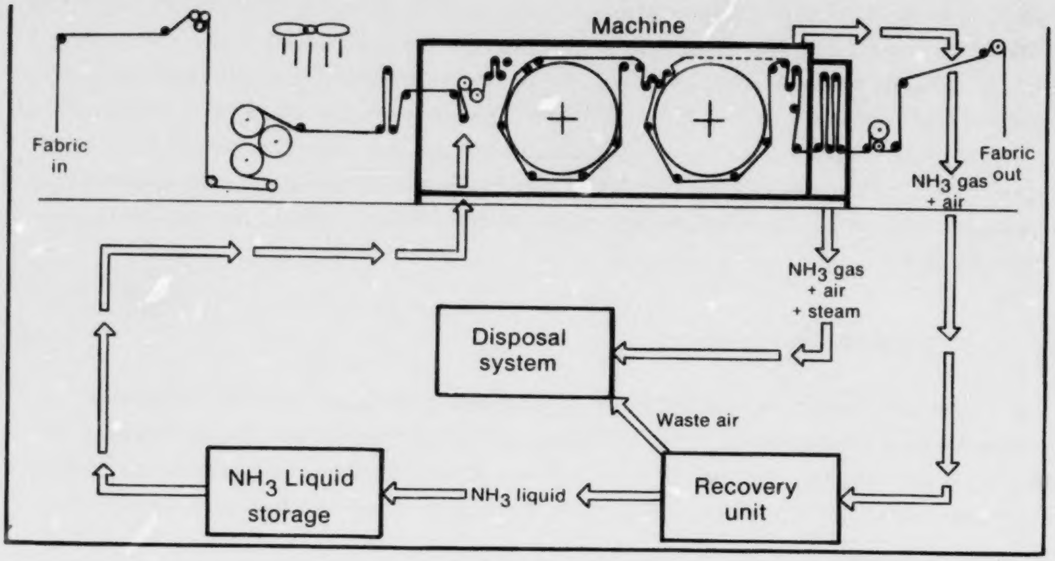


FIGURE 6-44

FABRIC FLOW IN THE DURALIZED PROCESS, SHOWING THE MAIN COMPONENTS OF THE LIQUID AMMONIA RECOVERY SYSTEM

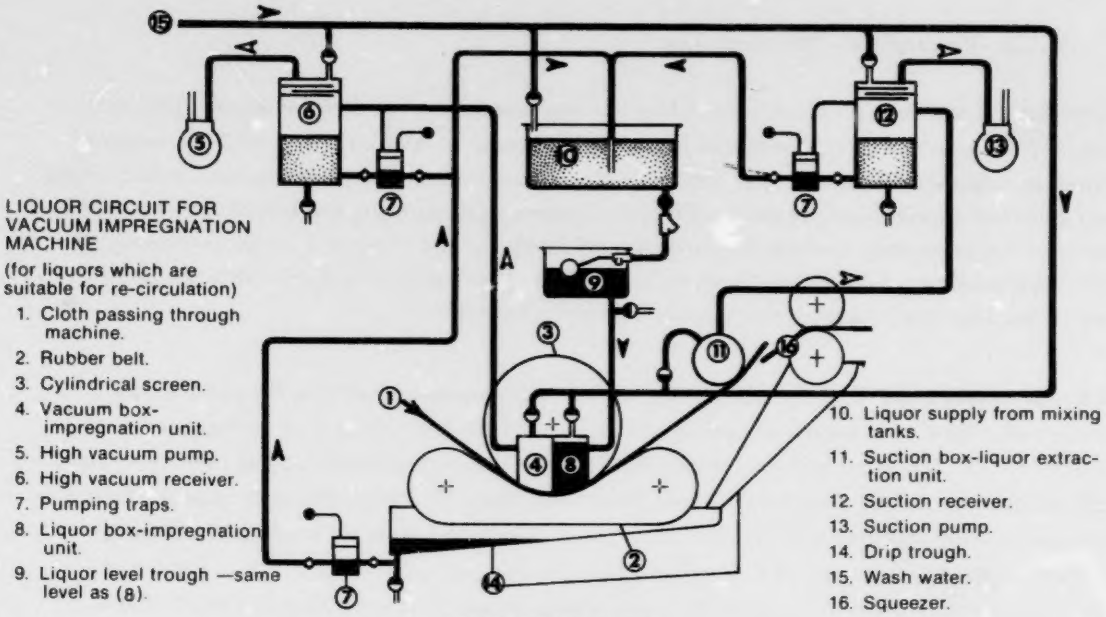
About 5% still remains attached to the fabric and is removed next by light steaming. This ammonia-laden steam is collected and sold as ammonium hydroxide for fertilizer manufacture.

This commerical application is the major process use of liquid ammonia today. It is indicated that liquid ammonia may also be marketed as a replacement for caustic mercerization. Although luster is said not to be as great as by caustic mercerization, the shrinkage stability, crease recovery, and smooth drying may be better (46). Dyeing applications appear to have cooled considerably as this point. No commercial dyeing equipment has yet been demonstrated.

6.5.2.16 Vacuum Impregnation

It was reported in 1971 by ICI investigators that when fabrics, particularly heavy weight goods, are exposed to high vacuum and then immersed in liquor, they become completely saturated with the liquor (63). Under normal pad procedures, short dwell time often makes it difficult to impregnate heavy weight fabrics. Trapped air in the goods is said primarily responsible in preventing quick and complete fabric wet out. Therefore, the efficiency of liquor flow can be reduced along with chemical penetration and levelness. Vacuum impregnation overcomes these problems.

A commerical application of a vacuum impregnation unit used in dyeing corduroy fabrics was reported in 1972 (64). Fabric in the system comes into contact with a perforated stainless steel cylinder from which a vacuum pump draws air. The fabric hugs the surface of this cylinder closely via an endless rubber belt which acts as a seal for the applied vacuum. The perforated



LIQUOR CIRCUIT FOR VACUUM IMPREGNATION MACHINE

(for liquors which are suitable for re-circulation)

1. Cloth passing through machine.
2. Rubber belt.
3. Cylindrical screen.
4. Vacuum box-impregnation unit.
5. High vacuum pump.
6. High vacuum receiver.
7. Pumping traps.
8. Liquor box-impregnation unit.
9. Liquor level trough —same level as (8).
10. Liquor supply from mixing tanks.
11. Suction box-liquor extraction unit.
12. Suction receiver.
13. Suction pump.
14. Drip trough.
15. Wash water.
16. Squeezer.

FIGURE 6-45

SCHEMATIC OF FARMER NORTON VACUUM IMPREGNATOR

cylinder acts as a combination vacuum-liquor tube, and the fabric and dye liquor come into contact prior to the fabrics return to normal pressure. Operating speed is up to 100 yds/min. A schematic of the equipment valued at approximately $20,000 is shown in Figure 6-45.

Vats, sulfur and reactive dyestuffs were successfully used in this process. The economy and advantage of this system is felt to be in that much of the goods preparation can be bypassed. Furthermore, reworks may be minimized.

The process may also be applicable to durable-press resins, i.e., goods not getting uniform penetration of the resins due to rapid production speeds and short baths. The problem is that resins buildup on the fabric surface and crosslinking occurs at the fiber surface. This can lead to low DP performance and low abrasion resistance. This equipment was reported in 1973 as having considerable potential in supplementing conventional operation (65). Balance must be struck in considering the migration effects caused by drying also.

The promise, although not yet demonstrated full-scale, is that polyester doubleknits, textured polyester, acrylic-based fabrics, and fiberglass fabrics have been satisfactorily vacuum impregnated in production dyeing trials. Furthermore, unscoured knits containing knitting lubricants have also been evenly dyed with pilot-scale equipment. Bleaching was also said to give the same degree of whiteness, more uniformly with less chemical used, and in less time than by conventional means. The environmental advantages strongly indicated are that reduced production sequences (less water) may occur, and if less chemical is used more efficiently, then less discharge of chemical will occur. General application does not appear indicated, but specific situations may warrant consideration.

6.5.3 Preparation – Developments

Kiers for the scouring of cotton are tending to disappear because of their incompatibility with some of the more modern concepts of finishing. Furthermore, kier-boiling operations are more prone to suffer from human frailty and to produce more undesirable problems than semi-continuous and continuous bleaching ranges. The use of open-width scouring and bleaching is tending to increase for processing medium-to-heavy weight fabrics at the expense of rope processing for two reasons. One reason is that creasing tends to be eliminated, which can show up in later processes. The other reason is that less weft distortion occurs.

It has been said a number of years ago that cloth continuously prepared in the open-width while under light warp tension is considered by many dyers and finishers to be the prime condition to obtain highest quality dyeing and finishing (66). Scouring and bleaching under pressure offered early promise for operating under these conditions. By 1968 at least six manufacturers offered pressure equipment (67). The major problem in each case was the pressure-retaining seals. In 1966, Riegel reported success with pressure scouring of 8½ oz. of cotton goods (68). Riegel reported caustic scouring in the open-width in one minute at 27 psig (about 2 atm., 270° F). Problems encountered at that time included misalignment causing wrinkling and turned selvages, a slow heating up and cooling down time (5 hrs) when seams break, lint buildup behind entry seal rolls, frequent replacement of seals, and rapid wearing out of the saturator rolls. Major advantages were said to be less chemicals used, rapid treatment and correction of errors before too much fabric was improperly treated.

Since 1966 Riegel's pressure scour has fallen into disuse, just as did certain other one-stage scouring and bleaching processes. Neither produced the desired results for wide-spread commercial application.

By 1975 the concept of pressure scouring and bleaching experienced a revival in the U.S. (69). Improvement in seals and separation into two-stage operation were seen to be the major modifications (70). In 1973 two-stage pressure scour and bleach were to be employed to handle 125,000 yds/day with substantial reduction in costs of chemicals, water, steam and labor (70). A possible sequence for single-stage scouring is shown in Figure 6-46.

Another manufacturer offers a variation (Kleinwefers 100+ unit) of the concept of pressure scouring. In this equipment, cloth is horizontally led upwards in a saturated steam environment of 230° F. Meanwhile, liquor proceeds downward. Heated liquor is pressed by deflection rolls through the fabric and then is channelled to a collection vat and led on to the following cloth width below. It is said the best working pressure appears to be 7 psig (232° F), with caustic at 5%. No U.S. reports are available at this time discussing use of this equipment.

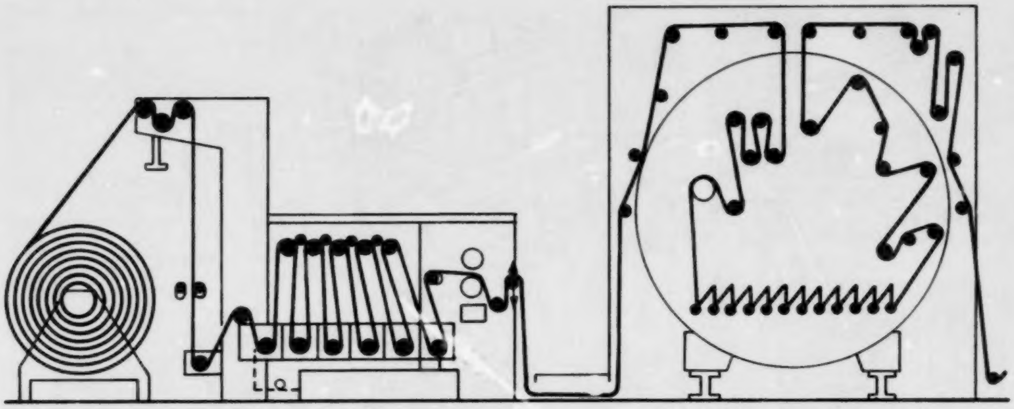


FIGURE 6-46

SINGLE STAGE SCOURING SYSTEM

6.5.3.1 Mercerizing – Development

The 100-plus-system discussed previously is also said to offer several advantages in comparison with conventional washing machines after mercerization. The washing effect of three 100-plus units is said comparable to that of six conventional machines. The main advantage of the equipment is said to be that the total volume of water may be fed into the mercerizing compartment without loss. Although no machines are known to be operating in the U.S. at this writing, several are operating in Europe (71). The fact that the system is said to offer no environmental pollution by waste caustic, reduced water and steam consumption, and reduced space requirements makes it worthy of investigation. The system is shown in Figure 6-47 as it follows a chainless mercerizer.

Before leaving the area of mercerization, it was reported in 1973 that a mill mercerizing corduroy modified conventional processing by steam spraying the bottom of the goods on the tenter frame (69). This reduced acid requirements in later stages. Furthermore, three "S-laced" washers, operating at 208° F, neutralized fabric without acetic acid. This procedure saved the firm more than $400/day in chemical costs alone.

It is also suggested that the more reproducible mercerizing liquor is kept, the better and more uniform results will be. Research suggests that optimum mercerizing effects (swelling) are obtained with a liquor of 52.2° Tw (72). This is achieved quickest in production around 63° F. Some say it is essential to keep the temperature constant, and cooling units are available which pump Freon through the system. Control thermostats can keep temperatures between 50 and 68° F. The wetting agent is also important and cotton should be wet out in 3 to 5 sec. The fiber needs to be penetrated to the core before the peripheral zone is fully-swelled. Wetting agent concentration and wetting time, in certain instances, can alter the color of the cotton. Chemically

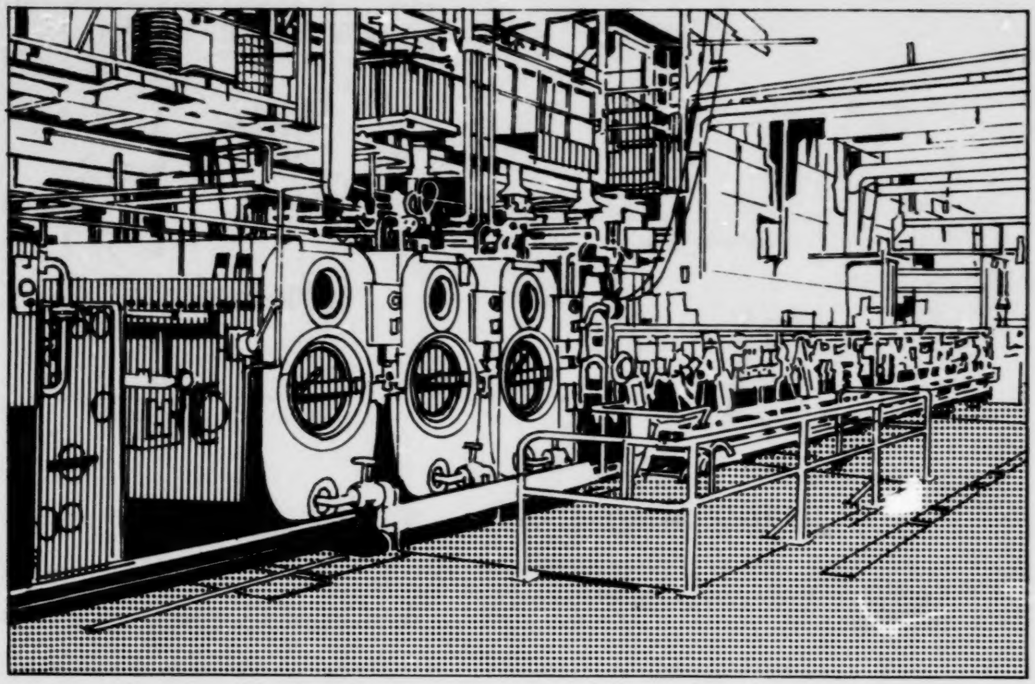


FIGURE 6-47

CHAINLESS MERCERIZER AND THE 100-PLUS-SYSTEM. BETTER ECONOMY OF PRODUCTION BY SIGNIFICANTLY REDUCED WATER AND STEAM CONSUMPTION.

speaking, mercerization will be uniform when caustic and wetting agent concentrations are constant and liquor temperature is kept constant. This research indicates the potential for the greatest economy in chemical and water usage.

On the other hand, advocates of hot mercerizing say rapid penetration to the fiber core produces a more easily stretched fiber-fabric, with better subsequent chemical processing, and better finished fabric properties (73). These results are said to be accomplished at lower cost, energy, water, and chemicals than by conventional mercerization.

6.5.3.2 Knit Dyeing

The availability of even proven new technology does not necessarily mean universal acceptance will occur. This is also true in cases where the technology may have minimal water and energy requirements. Knit dyeing is such an unsettled area currently, and a short overview may provide insight and perspective to some of the forces opposing acceptance of new technology and processes.

In the recent past, paddle, skein, and package dyeing of knitting yarns predominated. The introduction of fabric dyeing was accompanied by the use of atmospheric becks. Relatively large volumes of water are used in these processes which also often result in high strength wastes. Difficulties in dyeing newer textured polyester doubleknits next promoted an increase in the use of pressure becks. Since increased pressures allowed use of less carriers, this was an advantage in decreasing waste strength. Efforts to improve beam equipment and overcome flattening problems saw innovations such as the jet air principle. Introduction of the jet dyeing machine saw widespread acceptance gained because jet machines promised to overcome problems of crease marking, rope marks, tension, and distortion. Jet machines compromised in principle between the technically more favorable procedure of circulating liquor through fabric and the less-efficient procedure of circulating goods through a bath. Although problems such as foaming were still of considerable trouble, jet equipment generally used less water and energy and reduced waste strength. The next step appeared to be towards overall more efficient processing, less water use, and minimally polluting waste waters by continuous open-width methods. As early as 1971, continuous knit open-width dyeing and washing machines were operating in the U.S. The equipment was said to be versatile enough for use in desizing, scouring, and bleaching also. Cost was $150,000 in 1971. Major criticism concerns lack of control over curling fabric and tension effects (stretching).

Below, a schematic indicates the major advantages of a jet dye machine over the winch or beck, Figure 6-48.

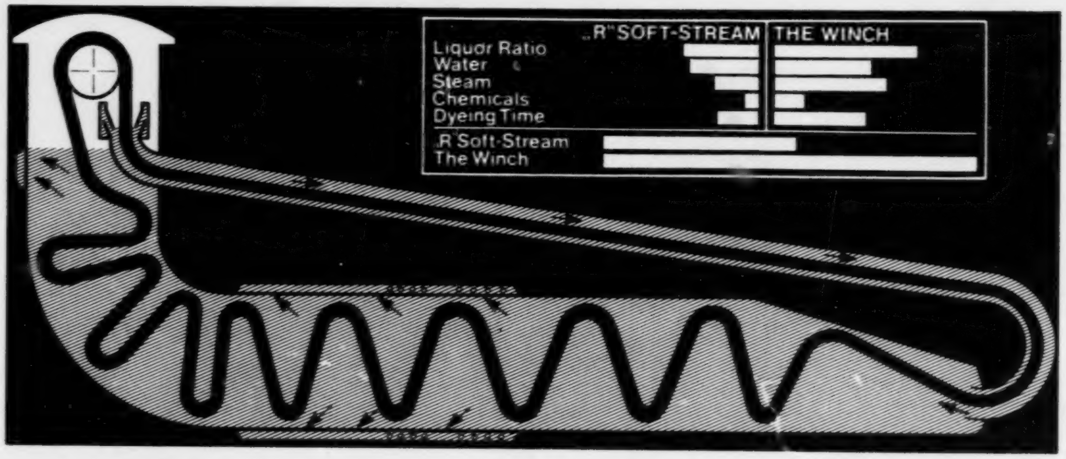


FIGURE 6-48

ENVIRONMENTAL COMPARISONS OF JET DYEING vs. BECK DYEING

6.5.3.3 Immersible Dyeing Systems

McNally (William Heller Co.) discussed the virtues of the immersible dyeing jet (fully-flooded) (74). The main advantage of such a system was said to be its potential for removing dye stain defects. A side-tank feature allows removal of agglomerated dyestuffs which cause such problems. Other advantages of this equipment included the absence of foam and associated problems, absence of scum lines, leveling of streaky and blotchy goods, high degree of shade reproducibility, and a high production rate. The main pollution advantages are that this equipment allows reduced cleaning prior to following batches and reduced temperatures (dropped from 275 to 265° F for polyester dyeing). McNally finds brighter shades are produced in the pure, no carrier method. Besides polyester, Qiana and some acrylics appear to run well.

6.5.3.4 Sancowad Dyeing Process

Gaston County offers the Aqualuft Jet Dyeing Machine and the Sandoz Sancowad Process (invented by G.H. Lister, Sandoz). The principle in essence is that fabric is impregnated with dyes suspended in a micro-foam. The process is started cold to minimize dye substantivity. After uniform distribution through the fabric, temperature is raised to provide dye fixation to the fabric. The major advantage is low liquor, material ratios of about 1:1, and consequent lowering of the effluent volume (see Figure 6-49).

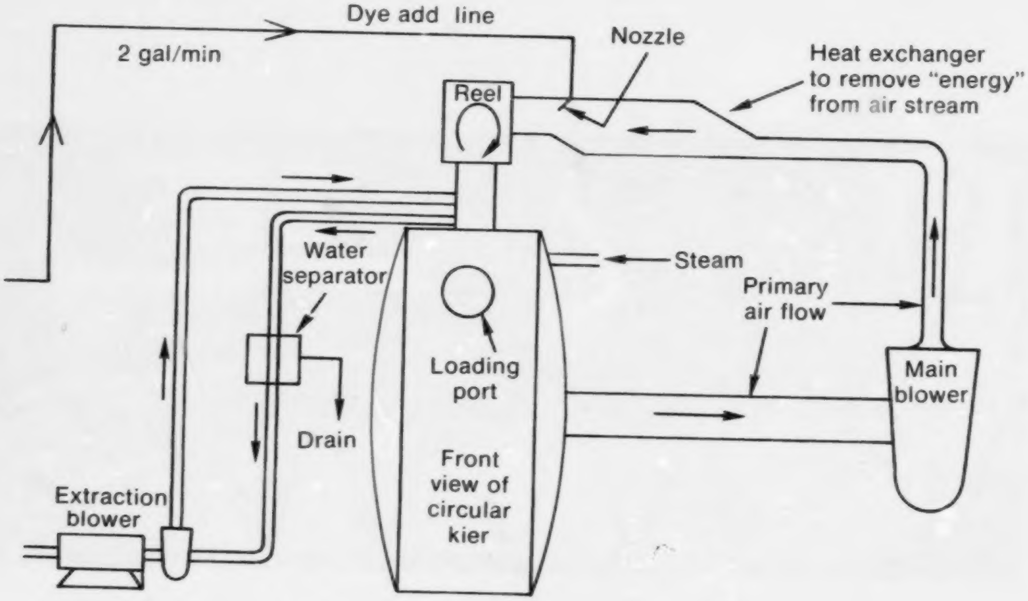

Dye add line
2 gal/min
Nozzle
Heat exchanger to remove "energy" from air stream
Reel
Water separator
Steam
Primary air flow
Loading port
Main blower
Drain
Front view of circular kier
Extraction blower

FIGURE 6-49

SCHEMATIC OF AQUALUFT MACHINE

Resource comparisons were given between Gaston's H-Jet Machine (represents conventional jet dyeing machine) and the Aqualuft for one cycle.

	H-Jet	*Aqualuft*
Total Water	10,800 (75:1)	1,140 (10:1) (13% of H-jet)
Total Steam	2,530 lbs.	630 lbs. (25% of H-Jet)
Total Electricity	240 kilowatt hours	330 kilowatt hours (140%) of H-Jet)

Claim was made that fabrics (woven and knit) may need no prescouring, and that textured polyester was dyed with PVA size on, and that the system lends itself to high energy dyes which normally give barre'. These features were mentioned to offset the high equipment cost because if there were no water pollution problems and energy considerations, it might otherwise be difficult to justify the Aqualuft over conventional jet dyeing equipment. Balmforth reported favorably on the feasibility of the system and cited the plus values concerning energy and pollution (9). He cautioned that the equipment was high cost and was emerging technology with little substantive data on its use beyond the manufacturer's claims. The first commercial installation of the Sancowad dyeing process is using 20 to 25% less dye than the standard paddle method. Cormier Hosiery, Laconia, N.H., who purchased the system from Bentley-Pegg, also are saving 80% of the usual water used, with savings also noted in steam and electricity (75).

6.5.4 Reduced Processing Sequences

6.5.4.1 Concurrent Slashing and Dyeing

Reducing processing sequences can provide an economy in water and chemical use and discharge. In 1972 Atlantic Chemical Corporation reported three U.S. firms were using the Padazoic slasher-dyeing system to process denim (76). About 50,000 yards of fabric were said dyed by the system without dyes or water being discharged to local waters. In March 1975 about 300,000 million yards were reported processed (77). Another benefit asserted was that a stronger yarn is produced, since it is processed with all its impurities. This is said to aid weaving performance, and reduce cotton waste. Recently, equipment developers have improved on the system and have marketed newer versions. This form of modification should be considered where feasible as a replacement for indigo dyeing.

6.5.4.2 Concurrent Dyeing and Finishing

A number of years ago several classes of water soluble dyes were applied concurrently with resin precondensates with the intent of simplifying the finishing process. The environmental savings in energy, chemical and water usage are potentially great enough to suggest that consideration be given to such systems. In this work selected acid and direct dyes were applied to cotton by placing them in a resin finishing bath, padding on, and curing (78). Several resin systems were studied.

The results showed that covalent bonding of the dye structure to the resin system was not absolutely necessary. By choosing suitable disperse colors, a polyester/cotton blend was also dyed with a simple pad-dry-cure procedure. If the resin is fully cured at the plant, a dyer has the advantage of seeing the final shade without having to coordinate two separate procedures.

6.5.4.3 Transfer Printing

In its present form, transfer printing is only suitable for some synthetic fibers. It has been particularly successful with polyester, and some transfer printing has been done on acrylic, nylon 66, and triacetate. Some wool has been successfully printed by means of the so-called Fastran process after a pretreatment. A further breakthrough in transfer printing on natural fibers is not clearly foreseeable at the present time in the same simple way.

Due to the nature of the present transfer process as well as to the low quantity of dyestuff delivered to the paper, the penetration of the dye into the fiber is limited. This is a particular problem with knit goods as the base color of the substrate becomes visible when the cloth is stretched.

Many other advantages and disadvantages, such as high paper costs, exist, but within the limitations of this discussion, only a few more pertinent points will be made. Rapid developments can be anticipated in vacuum transfer printing systems and new dye formulation technologies; good results are already discussed using existing rotary screen printing equipment. Stork suggests production speeds up to 90 yds/min. with a two section dryer are practical with paper.

Important advantages from the viewpoint of this discussion are:

- Dyestuff consumption is considerably lower than with direct printing on textiles. A dye yield of 80% can be realized with printed paper, and penetration can be better controlled.

- Hardly any water is consumed leading to less environmental pollution because there is no need of aftertreatment.

- Considerably less energy is consumed during drying. Approximately one-half ounce of water per square yard is used in transfer printing compared with approximately 3½ to 7 ounces of water per square yard used in direct printing.

- No aftertreatment such as steaming, washing, or drying is required and results in lower cost, less production space, less skilled personnel requirements, and less pollution.

A piece of equipment offered by one vendor performs in the following manner. At the front of the unit, transfer paper, fabric, and backing paper (when necessary) are fed into the nip. Figure 6-50 shows the schematic cut away of one piece of equipment and the actual equipment of another vendor (79), (80).

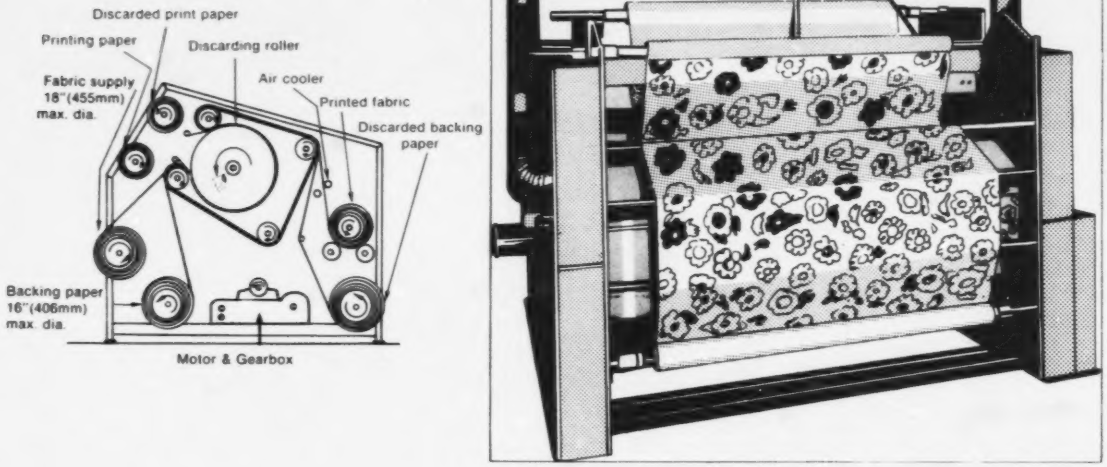

Discarded print paper
Printing paper
Discarding roller
Fabric supply 18"(455mm) max. dia.
Air cooler
Printed fabric
Discarded backing paper
Backing paper 16"(406mm) max. dia.
Motor & Gearbox

FIGURE 6-50

TRANSFER PRINTING EQUIPMENT

Heat is applied and is controlled within 212 to 414° F. In this particular unit the paper and fabric are taken around the heated cylinder by a Nomex endless blanket, and then each one is rolled up again at the rear with controlled tension. The fabric is cooled before the roll up.

6.5.4.4 Process Controls

In February 1974, R.J. LeBrun (Foxboro Co.) stated textile industry lags far behind other industries in adopting new control concepts (81). A major reason suggested was early failures of computerized systems. LeBrun feels that major improvements resulting in the past 5 years warrant attention. He stated about 10 companies are now using computers to direct sequential machine functions with a few companies computer operating continuous operations. Foxboro is currently automating a continuous finishing plant in Europe, composed of a bleach range, thermosol dye range, tenter frame and print steamers. LeBrun said the Foxboro Textile Dye Control System is feasible for 8-plus atmospheric, pressure, jet, beam and package machines. The system is said able to provide the necessary sequential controls to handle up to 30 machines of any combination at the same time.

Freeman (Foxboro) discussed the whys and hows of computer control of textile operations in detail (82). Neish (Taylor) described the use of a digital computer to improve the effectiveness of dyehouse management in a two-series article (83). The schematic of the Taylor 1010 system for dyehouse control is shown below (see Figure 6-51).

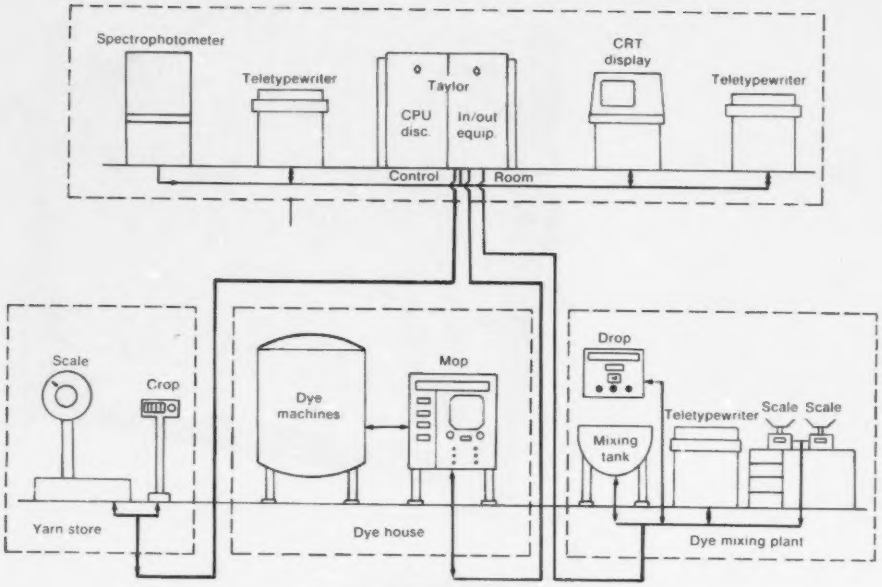

Spectrophotometer
Teletypewriter
Taylor
CPU disc.
In/out equip.
CRT display
Teletypewriter
Control
Room
Scale
Crop
Yarn store
Dye machines
Mop
Dye house
Drop
Mixing tank
Teletypewriter
Scale
Scale
Dye mixing plant

FIGURE 6-51

TAYLOR 1010 SYSTEM FOR DYEHOUSE CONTROL

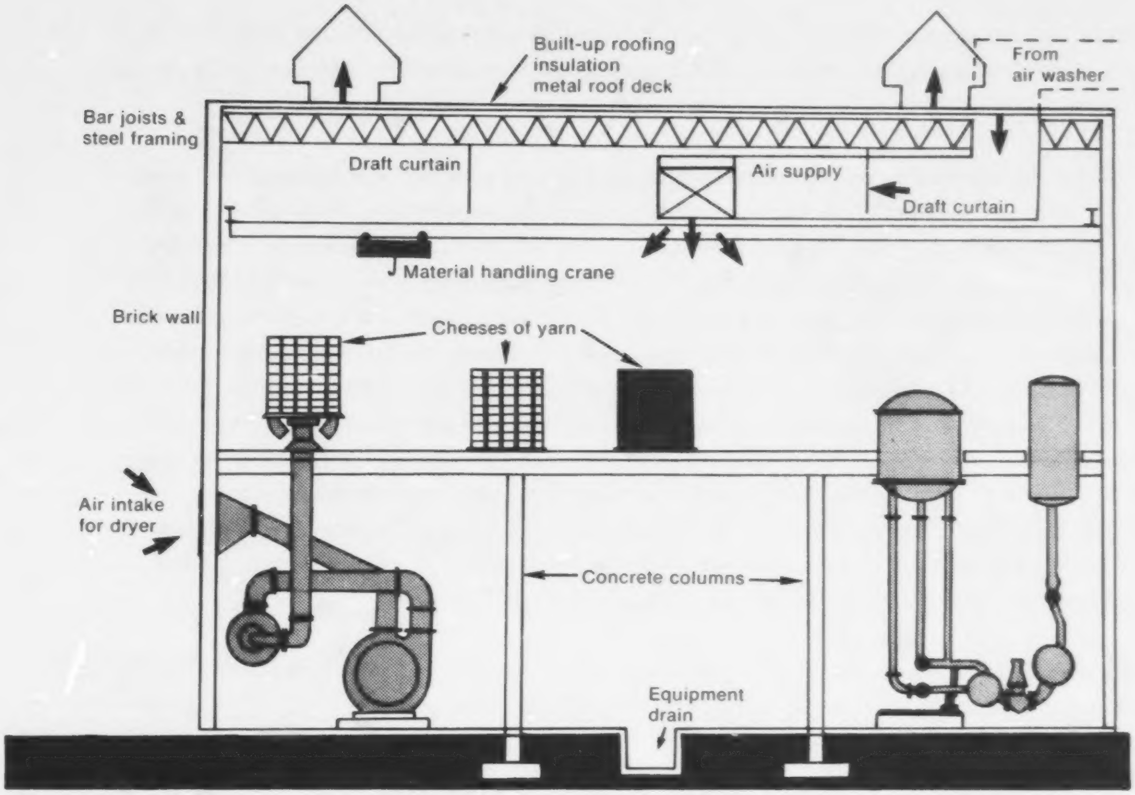
Burlington Engineering Sales, Dye Control Systems, Inc., Gaston County and Steel Heddle representatives presented their equipment line features and discussed advantages of automatic controllers (84). Essentially, within the scope of this manual the main advantages include:

- Reduction in utilities used
- Less waste of chemicals and dyestuffs
- Reduction in redyes
- Reduced cycle times

Morris Gelders suggested a layout for a package dyeing operation in 1971 (85). Gelders felt steam and water usage could be reduced by one-third, less chemicals and dyes could be used, and heat could be reclaimed (see Figure 6-52).

Avondale Mills plans to install an advanced energy-saving dyehouse control system.

The system, designed by Process Systems, will control Morton beam-dyeing machines in the company's Bevelle Plant in Alexander City, Alabama.


Built-up roofing
insulation
metal roof deck
From
air washer
Bar joists &
steel framing
Draft curtain
Air supply
Draft curtain
Material handling crane
Brick wall
Cheeses of yarn
Air intake
for dryer
Concrete columns
Equipment
drain

PROPOSED LAYOUT of package dyeing operation is depicted in this schematic drawing by Lockwood Greene Engineers of Spartanburg, S. C. This dyehouse, intended for processing sewing thread and knitting yarn of synthetics and cottons, has bays 40 by 50 feet with channel slab roof deck. Winding and warehouse space have bays 40 by 40 feet with metal deck. The structure consists of an all steel frame with brick and block walls. In the dyehouse are keirs, vacuum extractor, and Avesta dryers.

FIGURE 6-52

In addition to providing the advantages of computer-controlled dyeing, the PSI 1210 system has two new features previously unavailable to textile companies:

1. The system will monitor and report consumption of electricity, steam, hot and cold water, and untreated water for each machine. The dyes will receive a report on all utilities and amounts of energy and utilities used per pound of fabric dyed. Machine malfunction, inefficient dye cycles, and excessive use of utilities can be easily spotted and corrected with this report.

2. Labor and production reports on each shift, each maning, and each worker are available with the PSI 1210 system. Machine production, down time, and operator delays are logged by the system and are available to the supervisor on a display tube or to management in printed form. Reports can be generated each shift, for daily production, or as a weekly summary of machine and labor performance.

An Avondale spokesman said the savings in energy and the increased efficiency of the new dyehouse control system will be a considerable improvement over conventionally controlled dyeing machines.

Where should one start in an automation program? Waiting to build a new dyehouse or "going all the way when we start" have been voiced as primary reasons why some have not begun. This does not have to be the case. There are immediate areas which one might consider. First, list problem areas, and categorize the priorities for solutions. Following is an example of the application of simple control equipment where money should not be wasted if a more complex system were to be installed later (86). A basic atmospheric dye beck for polyester/cotton might have 7 filling operations, 8 rinses and 22 separate temperature and time control settings. There are thousands of gallons of water used, and an operator in charge of several becks can waste considerable amounts due to overfilling and extended rinses. Better manual control of water usage would result in longer labor time. A time/temperature programmer could reduce errors, and save time, labor, energy and chemicals. A little more sophisticated might be equipment, such as the Celcon 3002, which allows automatic programming of time/temperature control and automatic operation of filling, draining, rinsing and addition valves.

Eslick reported a comparison between two plants within American Thread using essentially the same formulations (6). One plant was automatied while the other was not. Substantial improvements in various areas resulted in the automated plant. Plans are to automate further and to computerize raw water treatment, boiler operation, dyehouse operation and waste treatment operation in both plants.

6.5.4.5 Minimum Application Machinery

Burkitt (11C) suggested in 1974 that after conventional easy-care finishing, most of the resin lies on the fabric surface and that this contributes to poor fabric wear life (87). Study indicated that the uneven distribution of chemical was, in large, due to migration during drying. It was felt that reducing the amount of water applied with the resin could improve on migration effects. It was suggested that water be removed from the usual 60 to 70% wet pick-up to 30%. About the time the principle was being demonstrated on a laboratory scale, i.e., improved easy-care performance with less chemical, Triatex AG of Zurich marketed a commercial machine. Both methods of application required lick roller application of the resin solution. The Triatex equipment is shown in Figure 6-53.

The results of using this equipment suggested that improvements in losses of durability might occur in 100% cotton goods, less chemical might be required, less energy might be needed in drying, and processing might be shortened.

The increase in efficiency implied by this system, and its resultant environmental benefits, must be balanced by the fact the technique may not be suitable for continuous, high-speed,

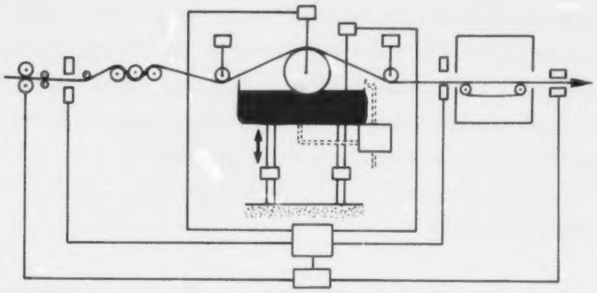


Diagram of Triatex MA machine showing how liquid add-on is controlled by roller speed and monitored by Beta gauge.

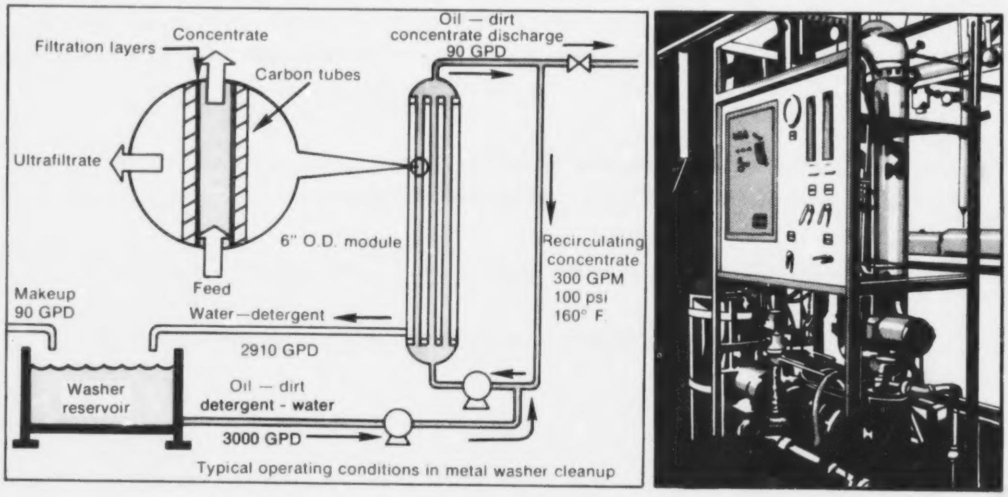
FIGURE 6-53

TRIATEX MA SYSTEM

full-scale operations. Lack of immersion time to provide adequate diffusion of material into the fiber under usual processing conditions is cited as the primary disadvantage.

6.5.5 New Technology

It is also within the textile engineers domain to gauge the application of chemical engineering technology to textile processing. The reality of PVA size reclamation and reuse by Gaston County has already been mentioned. Union Carbide markets membranes similar to those used in the Gaston County equipment under the trade name of Ucarsep. This system is shown, Figure 6-54, removing and concentrating oil and dirt from a metal phosphating line. Also a photo of a pilot scale module is included.


Filtration layers
Concentrate
Oil — dirt
concentrate discharge
90 GPD
Carbon tubes
Ultrafiltrate
6" O.D. module
Recirculating
concentrate
300 GPM
100 psi
160° F
Feed
Makeup
90 GPD
Water—detergent
2910 GPD
Washer
reservoir
Oil — dirt
detergent - water
3000 GPD

Typical operating conditions in metal washer cleanup

FIGURE 6-54

PROCESS IMPROVEMENT PLUS POLLUTION CONTROL

This equipment is said to be capable of withstanding temperatures up to 200° F, pH's in the range of 1 to 14, and pressures up to 100 psi (88). The equipment suggests itself for starch and CMC size removal, dye reclamation, mercerizing liquor clean up, latex removal, wool grease recovery, with reuse of hot cleaned water directly. With the development of tighter membranes, separation of smaller molecules, such as carriers, may be possible.

6.5.6 Process Changes Checklist

- Determine proper quality, quantity and temperature of water needed.
- Consider reclamation of heat from all wash water effluents.
- Counterflow as much as possible.
- Minimize quantity of water used in early rinse stages to suit operation requirements.
- Optimize cloth speed vs. water throughput as a function of fabric weight.
- Control steam quality and uniformity.
- Control to prevent excess use of steam.
- Use moisture meters to prevent over-drying.
- Determine absolute need for drying stages and evaluate addition of extraction before drying.
- Meter all chemicals into make-up tanks and processing equipment. Recycle overflows by proper piping.
- Establish minimum preparation standards, i.e., size removal, tensile strength, absorbency, and whiteness related to following process problems.
- Consider automation and computerization of plant processes.
- Consider proper sequencing of unit operations for minimum equipment usage.

6.6 Good Housekeeping

Good housekeeping practices must be a cooperative effort between management, plant personnel, and the maintenance crews. This cooperation must include continuing education, especially for the operating personnel, because a lot depends on them. It has been discussed (53) that, "The normal workday routine does not lend itself to an individual making extended efforts at correcting sloppy habits which have usually developed over a period of years." Once the easy things have been done the task should be concerned with how to motivate workers, keep their interest, and make them aware of the fact that top management also is concerned. A routine monthly meeting of supervisors might include this matter in the agenda. The success had by American Thread of appointing one man responsible for environmental and energy programs, should be noted as an excellent approach worthy of consideration.

Although good housekeeping practices do not bring about spectacular reductions in pollution loads or energy savings, they are indispensible to the goals of both concepts. Over the long term, significant savings can be realized and certainly benefit can be gained in the thought that safer working conditions should also be an advantage.

6.6.1 Spills

Focus can now be made on specific suggestions for good housekeeping.

Obviously, accidental spills, breakage, making of excessive mixes, and simply spilling excess chemicals down drains are some of the elements of bad housekeeping. Evidence of such spillage can often be detected by staining seen around drains. Oil or kerosene spills can be sopped up with Dow polymer imbiber beads. Toktuft, a Phillips 66 non-woven fabric, marketed by Gedcor Corporation, Westland, Michigan, is used to bag the beads. The bags are non-organic and can be safely disposed of by incineration. Other similar products are also marketed.

The humorous, positive-attitude posters, mentioned previously, can go a long way in keeping employees aware and alert that management's position is also an enduring one.

6.6.2 Organization

Better process organization may often be possible and should be considered. For example, installing a central drug room in the dyehouse where mixing of chemicals can be closely supervised is one possibility.

6.6.3 Automatic Shut-Off

A large reduction in overall water wastage can be simply achieved by fitting every water tap or hose with an automatic shut-off valve.

6.6.4 Records

Keeping records of production sizes and matching batch sizes can prevent making up too large batches.

6.6.5 Degreasing

If machinery requires degreasing, careful spreading of canvas and disposal by incineration are recommended.

6.6.6 Curbing

Curbs around equipment with adequate slope to drains can prevent dangerous spills and contain leaks.

6.6.7 Disposal Containers

Providing containers clearly labeled "trash" or "waste for incineration" is recommended.

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CHAPTER 7

WASTEWATER TREATMENT PROCESS SELECTION

7.1 Introduction

This chapter presents suggested wastewater treatment techniques for each of the EPA textile categories. Using average effluent wastewater characteristics and point-source limitations set for 1977, a suggested treatment model is developed and discussed for each category.

Upgrading treatment facilities to meet future limits (1983) will generally require the addition of one or more of mixed-media filtration, activated carbon adsorption, and chemical coagulation. Specific needs, however will be determined at the completion of reconsideration studies for 1983 (BAT) limitations.

7.2 Wool Scouring Wastewater Treatment

Wool scouring wastes are highly concentrated, and their treatment is both difficult and costly to the manufacturer or to the municipality which must cope with the material. Wool scouring mills, for the most part, are quite decentralized and in small units, so that the installation of waste treatment facilities represents a substantial capital investment.

The use of neutral detergent scouring to process wool has evolved through an effort to produce a waste effluent more amendable to subsequent treatment. Consequently, most of the wool scoured in the United States over the past 10 years has been by the neutral detergent scouring method. Also, along this same line of reasoning, if a new approach is used, either along the lines of solvent extraction or other modifications, it can have a pronounced effect on the waste treatment process and its associated cost.

In-plant recovery of wool grease is practiced by a number of mills with varying degrees of efficiency (usually less than 50%). Wool grease can be used in inks, paints, lubricants, and can be refined to produce lanolin. Methods of recovery include centrifuging and hot acid cracking. Recovery will substantially reduce the pollutant load to the treatment facility.

Characteristics of wool scouring effluent wastewater have been established in Chapter 4, and effluent requirements for point-source discharge are described in Chapter 2. These parameters and required removal efficiencies are summarized in Table 7-1 on the following page.

TABLE 7-1
WOOL SCOURING WASTEWATER PARAMETERS
(Point Source Discharge)

Parameter	Mill Effluent* mg/l	1977 Limit** mg/l	Percent Removal Required
BOD	6,000	296	95.1
COD	30,000	3848	87.2
TSS	8,000	898	88.8
Oil & Grease	5,500	201	96.3
Total Chrome	0.05	2.8	0
Phenol	1.50	2.8	0
Sulfide	0.20	5.6	0
pH (units)	8.0	6.0 to 9.0	—

*Mill Effluent values established as representative of processing subcategory, see Chapter 4.

**Effluent guideline limits based upon raw, not finished product. (Finished product is approximately 50% by weight of raw.) Values are 30-day average - Maximum for any one day is twice the 30 day average.

A treatment facility capable of achieving these removal efficiencies may be constructed utilizing a number of different processes. One such arrangement is presented in Figure 7-1.

In wool scouring there are two main wastewater sources; the scour water and the rinse water. The scour water is by far stronger and when segregated from the rinse waters provides the advantage of reduced treatment unit size. The initial effort in treatment of wool scouring waste is usually to remove the heavy solids such as grit, suint and the grease. Biological treatment may then be used to remove the remaining organic material. (Consideration may also be given to evaporation followed by incineration for concentrated waste streams.) The treatment process shown in Figure 7-1 is presented for meeting the BPT standards. Discussions of each unit process are presented in the following paragraphs.

7.2.1 Screening

A troublesome factor in the treatment of wool scouring waste is wool fiber within the waste. The fibers may come from improperly operated scouring equipment, washdown or other sources. The problems are encountered as the fibers degrade and cause odors and may also cause mechanical problems in pumps and other treatment equipment. It is usually necessary to provide coarse and fine mesh screening for removal of the fiber. Devices such as fine mesh vibrating screens have proven excellent for the removal of wool fiber.

7.2.2 Equalization

An equalization tank or basin is provided to receive the treatment scouring waste, the rinse waters after scouring, and supernatant from subsequent treatment processes. Equalization is required because of the batch dumps of waste, the surges and other flow variations which would upset downstream processes.

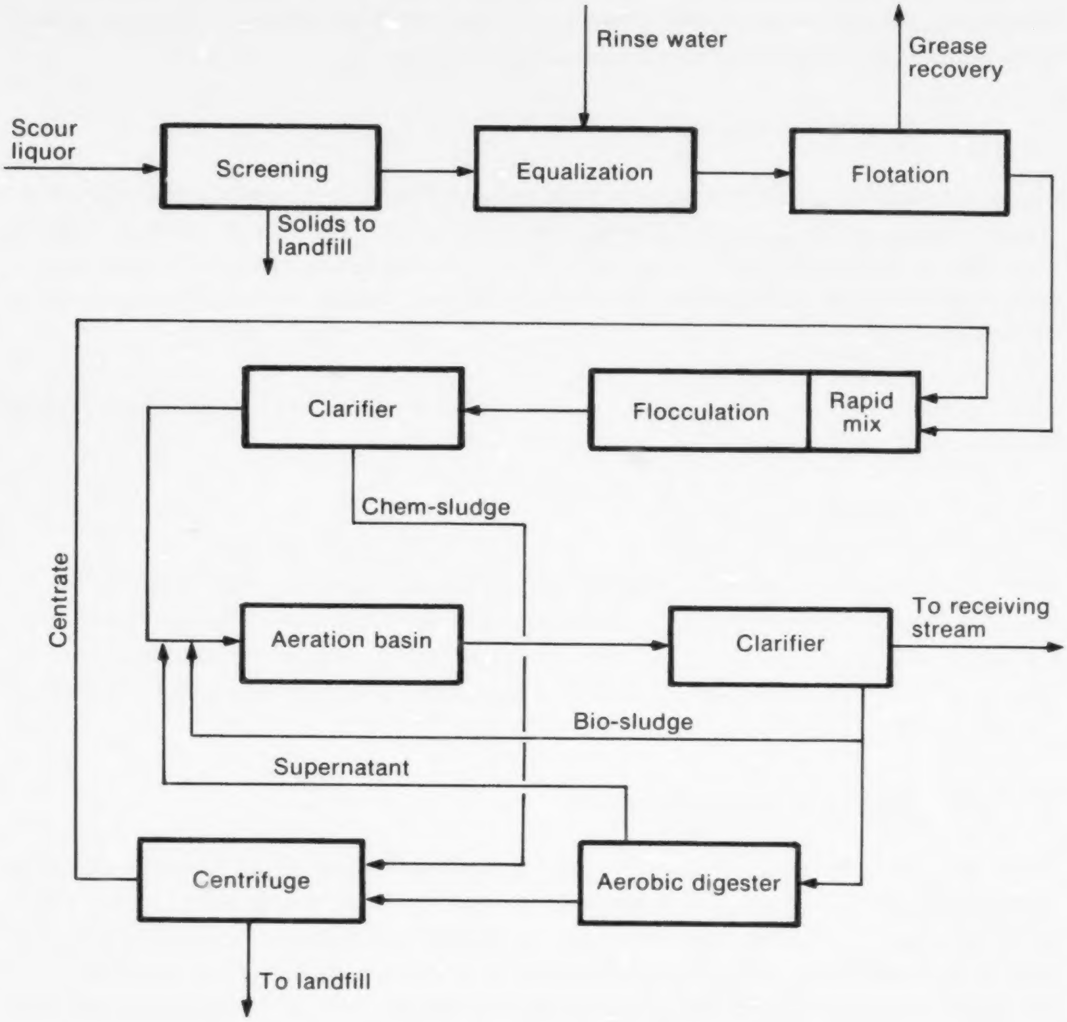
Scour liquor
Screening
Solids to landfill
Rinse water
Equalization
Grease recovery
Flotation
Clarifier
Flocculation
Rapid mix
Chem-sludge
Centrate
Aeration basin
Clarifier
To receiving stream
Bio-sludge
Supernatant
Centrifuge
Aerobic digester
To landfill

FIGURE 7-1

WOOL SCOURING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

7.2.3 Flotation

Flotation is provided to remove the substantial quantity of grease remaining after in-plant attempts at grease recovery. Floated grease may be returned to the grease recovery system and settled sludge can be dewatered with treatment-plant sludge.

7.2.4 Chemical Treatment

Chemical treatment is used to remove the high concentration of suspended solids composed of proteins, soaps and fibers. It can also reduce remaining oil and grease. These materials exhibit a high COD and turbidity which may be removed prior to biological treatment. Chemical coagulants suggested for use in this system are lime and calcium chloride. Ferric sulfate has also been used successfully.

The system consists of rapid mixing, flocculation and clarification. Upflow clarifiers with sludge blankets are sometimes used.

7.2.5 Biological Treatment

With most of the grease removed, biological treatment is used to remove BOD in the wastewater. Activated sludge has been successful in this, however, experience indicates extended detention periods of 10 to 20 days may be required. Food to microorganism ratios should be maintained at a low level (.03 to .05). Effective suspended solids removal is achieved with a low clarifier overflow rate of approximately 200 GPD/sq. ft.

7.2.6 Sludge Treatment and Disposal

Waste sludge from biological treatment is stabilized using aerobic digestion. The digested sludge is then dewatered by centrifuging. Supernatant is returned to the aeration basin influent. Dewatering using the centrifuge appears to have had some success with wool scouring wastewater sludges. Both the biological and chemical sludges are dewatered in a horizontal solid bowl type centrifuge. The centrate produced is returned to the rapid mix tank of the chemical coagulation process. Sludge from the centrifuge may best be disposed of in a sanitary landfill either on the site or off.

7.3 Wool Finishing Wastewater Treatment

Wool finishing mills are characterized as having the highest water usage per pound of product of finishing operations. Specialized dyes that are used may contribute chromium to the wastes. Dyeing of polyester blends involves the use of phenols. Most of the BOD is generated by washing after fulling and from dyeing operations. Chemical substitution such as the use of sulfuric acid in place of soap will substantially reduce pollutant loads requiring treatment.

With the exception of the chrome and phenol content, wool finishing wastewaters are similar in nature to those of woven and knit fabric finishing.

Wool finishing parameters for average mill effluent, limitations for point source discharge, and required removal efficiencies are summarized in Table 7-2 below:

TABLE 7-2
WOOL FINISHING WASTEWATER PARAMETERS
(Point Source Discharge)

Parameter	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	300	33.6	88.8
TSS	130	52.8	59.4
COD	1,040	244	76.5
Oil & Grease	—	—	—
Total Chrome	4	0.21	94.8
Phenol	0.5	0.21	58
Sulfide	0.1	0.42	0
pH (Units)	7	6 to 9	—

*Values are 30 day average - Maximum for any one day is twice the 30 day average.

Figure 7-2 represents the flow diagram of a treatment plant capable of achieving the 1977 effluent limitations guidelines. The facility would consist of screening, equalization, biological treatment and chemical treatment.

7.3.1 Screening

Wool fibers are removed using fine mesh type screens. Vibrating machines have been successful with these fibers. Suspended solids removals of up to 20% are possible with these screens.

7.3.2 Equalization

Equalization may be required if segregated chrome wastes are reduced and introduced into mill effluent, or if conventional activated sludge is selected as a treatment method. The equalization basin should be provided with adequate aeration and mixing to prevent solids deposition and septicity.

7.3.3 Biological Treatment

Activated sludge treatment may be best accomplished using extended aeration with a retention time of 3 to 4 days. If the conventional activated sludge system is used, equalization is suggested since the conventional method provides a retention time of approximately 6 to 8 hours.

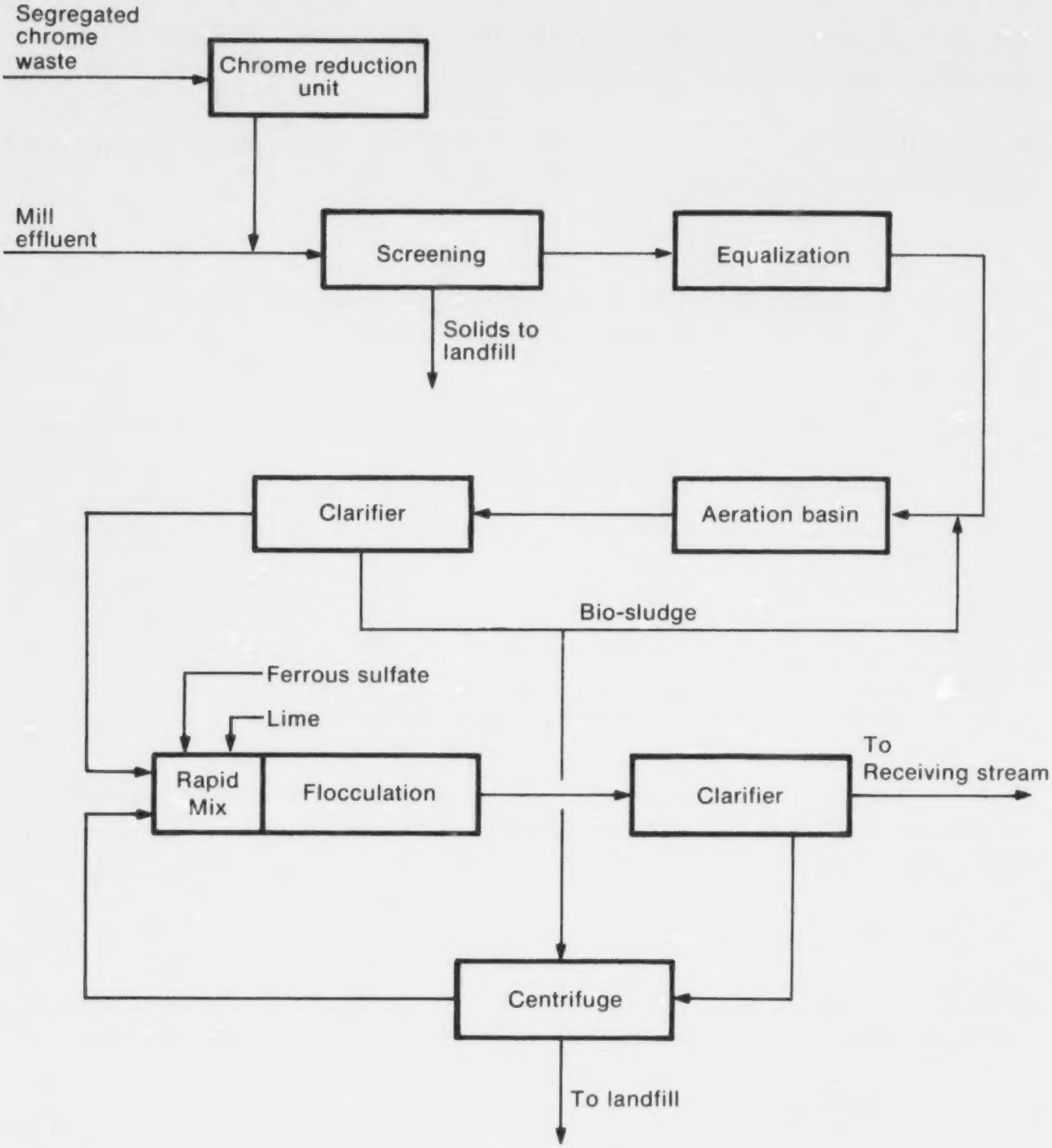
Segregated chrome waste
Chrome reduction unit
Mill effluent
Screening
Equalization
Solids to landfill
Clarifier
Aeration basin
Bio-sludge
Ferrous sulfate
Lime
Rapid Mix
Flocculation
Clarifier
To Receiving stream
Centrifuge
To landfill

FIGURE 7-2

WOOL FINISHING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

Nitrogen and phosphorus deficiencies have not been reported for wool finishing wastewaters. Excess ammonia nitrogen may be a problem in the effluent. If nitrogen is needed, ammonium sulfate used in place of acetic acid in processing will serve as a nutrient in the treatment system.

Chrome, if present from the dyeing process, may not upset the biological process even when present at concentrations of 50 to 150 mg/1 (as reported by Masselli). In addition, reductions of approximately 73% chrome have been reported for the biological process. If, however, chrome must be removed to meet stringent limits or to protect biological treatment, then it is suggested that, if feasible, chrome-bearing waste streams be segregated for separate treatment. At low flows, chrome reduction may be best accomplished using one of a number of package treatment units on the market.

7.3.4 Chemical Treatment

The chemical coagulation process is used as a tertiary treatment step to remove additional chromium and COD. Chemicals used for chromium reduction are ferrous sulfate (copperas) and lime. pH adjustment to 8.5 prior to entering the chemical coagulation process is necessary. The system would consist of rapid mix, flocculation, and clarifier tanks; however, solids contact clarifiers may be suitable.

7.3.5 Sludge Treatment and Disposal

A horizontal, solid-bowl centrifuge can be used for dewatering biological and chemical sludges. Biological and chemical sludge are to be fed to the unit separately at 1.5 to 2.5% solids. A cationic polymer is used as a conditioner at the rate of 10 to 20 pounds per ton of solids to yield a sludge cake of 12 to 15% solids. The centrate is returned to the rapid mix tank in the chemical coagulation process. Other sludge dewatering methods are available, as discussed in Chapter 8, and should be investigated. Sludge cake from the centrifuge may be disposed of to a landfill.

7.4 Dry Processing Wastewater Treatment

Dry processing wastes are generated at both greige mills and adhesive-related operations such as carpet backing, laminating, or non-woven mills.

Wastes at greige mills are composed of residues washed out of size boxes. Volume is small when compared to sanitary wastes at typical mills. The sanitary portion is generally 70 to 90% of total mill effluent. Treatability of greige mill wastes is related to the type of size used. Starch exhibits a high BOD and is readily biodegraded, while synthetic sizes such as polyvinyl alcohol or carboxymethyl cellulose exhibit much lower BOD and degrade more slowly as organisms take longer to acclimate to the synthetics.

Wastes from adhesive related operations are composed of bonding chemicals, mainly latex compounds. Latex generally enters the waste stream as washdown from equipment. The latex is not soluble in water but is used in a highly dispersed form and is therefore high in suspended solids and COD. Since the volume of process wastewaters is low, segregation and separate treatment may prove to be economical.

Representative mill wastewater parameters, effluent limitations for point source discharge and required removal efficiencies are summarized in Table 7-3 below:

TABLE 7-3
DRY PROCESSING WASTEWATER PARAMETERS
(Point Source Discharge)

Parameters	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	350	56	84
TSS	200	56	72
COD	1000	112	88.8
Oil & Grease	—	—	—
Total Chrome	—	.014	—
Phenol	—	—	—
Sulfide	—	—	—
pH (Unit)	10	6-9	—
Fecal Coliform**(MPN)	—	400/100ml	—

*Values are 30 day average - Maximum for any one day is twice the 30 day average.
**Max. Value

Figure 7-3 represents the flow diagram of a treatment facility capable of achieving the required removal efficiencies. The facility consists of screening, equalization, chemical treatment (adhesive waste only), biological treatment and disinfection.

7.4.1 Screening

Screens are provided for removal of sanitary debris and processing yarn and fiber. A comminutor may be required upstream on the sanitary line. Screens with mesh sizes in the 40 to 80 range are suitable.

7.4.2 Equalization

Equalization is used to combine process and sanitary wastes prior to subsequent treatment. Adequate mixing is recommended to prevent solids deposition and septicity.

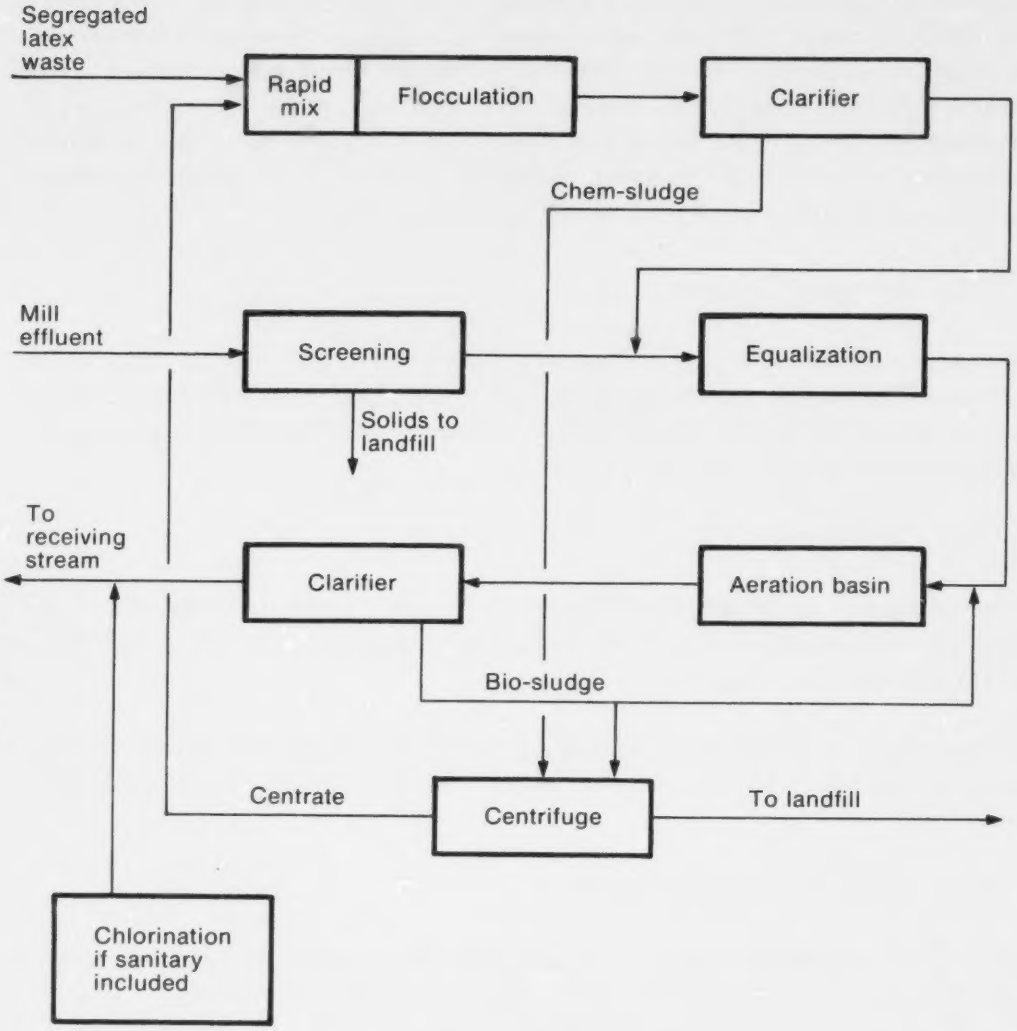
Segregated latex waste
Rapid mix
Flocculation
Clarifier
Chem-sludge
Mill effluent
Screening
Equalization
Solids to landfill
To receiving stream
Clarifier
Aeration basin
Bio-sludge
Centrate
Centrifuge
To landfill
Chlorination if sanitary included

FIGURE 7-3

DRY PROCESSING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

7.4.3 Chemical Treatment

The chemical coagulation process is used as a primary treatment for reduction of suspended solids and COD exerted by the adhesive compounds. (Greige mill wastewaters will not require this step.) This treatment is necessary because insoluble latex compounds are difficult to treat biologically. Coagulation may be accomplished using alum and a polyeletrolyte. Optimum pH and dosages will have to be determined in the laboratory. It should be noted that the physical characteristics of the coagulated sludge are important in terms of further dewatering and disposal, i.e., rubbery balls are sometimes formed in chemical treatment.

7.4.4 Biological Treatment

The conventional activated sludge process may be used because of the high percentage of sanitary wastes. Nutrients are generally adequate also due to the large portion of sanitary waste in the total effluent. If, however, sanitary and process wastes are segregated, a nitrogen source such as ammonia must be added to the process.

7.4.5 Disinfection

Dry processing mills are limited by guidelines in fecal coliform discharged in the effluent. Disinfection of process wastes will not be necessary if the sanitary portion is treated separately or discharged to a municipal system.

Chlorination may be selected as the method of disinfection. The system consists of chlorine feed equipment, 150 lb. liquid cylinders or calcium or sodium hypochlorite, and a chlorine contact tank.

7.4.6 Sludge Treatment and Disposal

The horizontal solid-bowl centrifuge has been effective in dewatering the dry processing waste sludge. Biological and chemical sludge enters the centrifuge at approximately 1.5 to 2.5% solids. A cationic polymer is used as a conditioner at the rate of 10 to 20 pounds per ton of dry solids to yield a sludge of 12 to 15% solids. The centrate is returned to the rapid mix basin of the chemical coagulation process. Sludge concentrated from the centrifuge may be disposed of in a sanitary landfill.

7.5 Woven Fabric Finishing Wastewater Treatment

In terms of number of mills and total pounds of production, woven fabric finishing is the largest single wet processing subcategory in the textile industry. Wastes are generated as a result of removal of foreign matter during cleaning and various chemicals used in finishing.

Composite plant wastes vary depending upon fibers processed; however, the effluent is generally high in BOD and COD with a modest suspended solids content. Small amounts of oil and grease appear from cotton impurities, and the pH may be alkaline from caustic soda scouring. Sulfide and chrome appear in the effluent from sulfur and vat dyes respectively.

In-plant controls such as caustic recovery, use of synthetic size, PVA reclamation and water use conservation will reduce pollutants and affect treatment plant sizing.

In Table 7-4, representative mill wastewater parameters, effluent limitations for point source discharge and required removal efficiencies are summarized.

TABLE 7-4

WOVEN FABRIC FINISHING WASTEWATER PARAMETERS
(Point Source Discharge)

Parameter	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	650	29.3	95.5
TSS	300	79	73.7
COD	1200	266	77.8
Oil & Grease	14	—	—
Total Chrome	0.04	0.44	0
Phenol	0.04	0.44	0
Sulfide	3.0	0.42	86
pH (Unit)	10	6 to 9	—

*Values are 30 day average - Maximum for any one day is twice the 30 day average.

Figure 7-4 represents the flow diagram for a treatment facility capable of achieving the removal efficiencies necessary to meet the 1977 effluent limitations guidelines. The facility consists of screening, biological treatment and chemical treatment.

7.5.1 Screening

Cotton impurities, fiber and other solids are removed by fine mesh screening. A screen with a mesh size of 80 has been effective for this application.

7.5.2 Biological Treatment

The activated sludge system is most effective for woven fabric wastes when designed as extended aeration with a retention time of 3 to 4 days.

Nitrogen deficiencies may be frequently found in woven finishing wastes. Aqueous ammonia or anhydrous ammonia may be added prior to entering the aeration basin. Sanitary sewage may

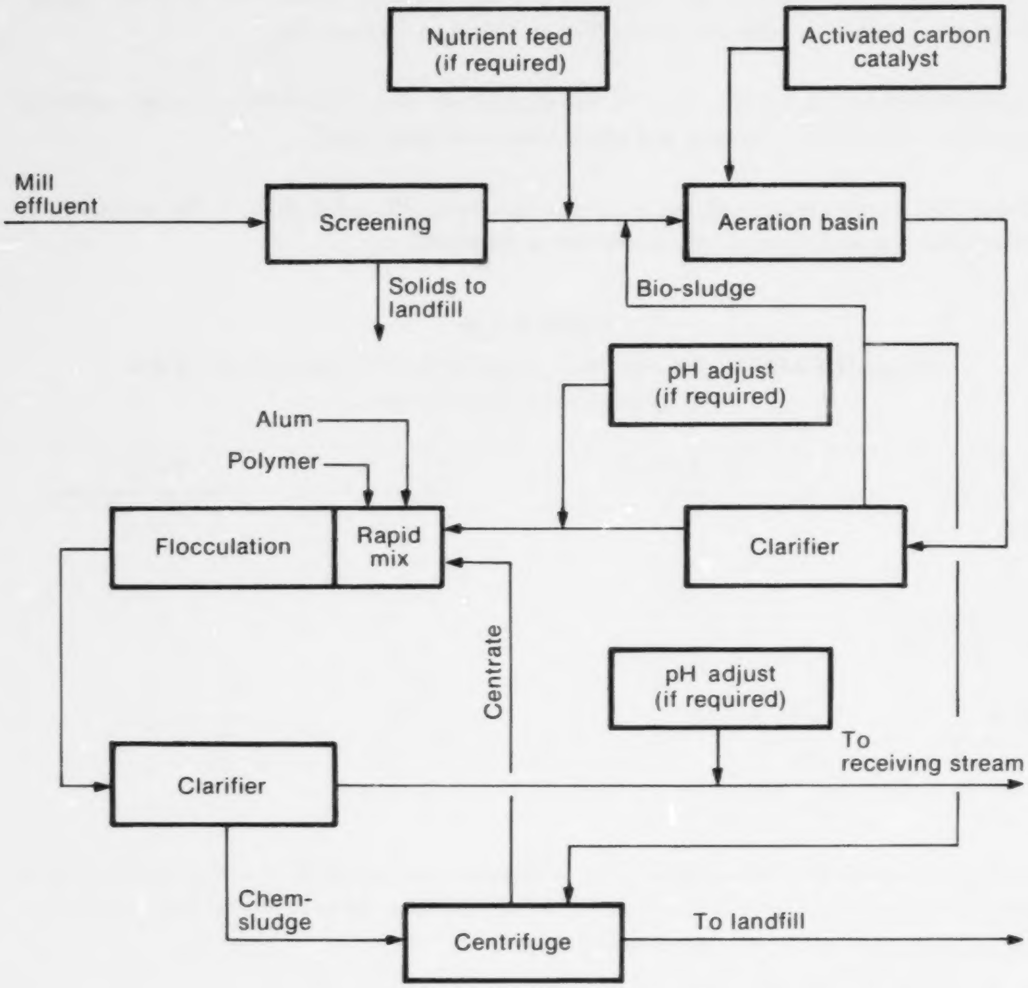
Nutrient feed (if required)
Activated carbon catalyst
Mill effluent
Screening
Aeration basin
Solids to landfill
Bio-sludge
pH adjust (if required)
Alum
Polymer
Flocculation
Rapid mix
Clarifier
Centrate
pH adjust (if required)
To receiving stream
Clarifier
Chem-sludge
Centrifuge
To landfill

FIGURE 7-4

WOVEN FABRIC FINISHING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

also provide a nitrogen source. Phosphorus content is generally adequate for the activated sludge system.

Foaming problems are common in the aeration basin and cannot always be controlled by conventional water sprays. Powdered activated carbon or a defoaming agent can be introduced to reduce or eliminate the foaming. Though not as effective as a defoamer, activated carbon will also act as a catalyst improving BOD, COD and color removal efficiencies of the biological system.

7.5.3 Chemical Treatment

The levels of BOD and COD removal required in Table 7-4 are difficult to maintain consistently with the biological system alone. Chemical treatment will serve to remove additional BOD, COD and TSS. Common coagulants used are alum and polymer. Optimum treatment may require lowering the pH. If so, pH adjustment before discharging the effluent may also be necessary.

7.5.4 Sludge Treatment and Disposal

Biological and chemical sludges may be dewatered using a horizontal solid bowl centrifuge. Vacuum filters have been tried but blinding problems have been experienced. Sludge is fed at approximately 1.5 to 2.5% solids and is pre-conditioned with a cationic polymer. The centrate is returned to the rapid mix tank. Sludge from the centrifuge may be suitable for disposal in a landfill. Other methods are available as detailed in Chapter 8.

7.6 Knit Fabric Finishing Wastewater Treatment

Knit fabric finishing mills are characterized by a large number of plants and a structure organized along specialized product segments. Knit fabric finishing operations are also similar to woven fabric finishing except that sizing/desizing and mercerizing operations are not required for knit fabric finishing. Instead, knit yarn is treated with lubricants rather than with the starch or polymeric sizes used for woven goods. Lubricants (knitting oils) are applied to knitting yarns and generally contain mineral oil, vegetable oil, synthetic ester type oil or waxes and may also contain anti-static agents, anti-oxidants, bacteriostats and corrosion inhibitors. The amount of oil applied varies with the type of yarns. Knitting oils are also injected into the needles of knitting machines in order to lubricate and lower the temperature of the needles. The knitting oil present in knit greige goods is readily emulsified or soluble in water and easily scoured or washed out before dyeing. Generally the mineral oil and scour detergents in the effluent are not readily biodegradable.

Table 7-5 represents the average mill raw waste load characteristics, effluent limitations for point source discharge, and required removal efficiencies of knit fabric finishing mills.

TABLE 7-5
KNIT FABRIC FINISHING WASTEWATER PARAMETERS
(Point Source Category)

Parameter	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	350	16.7	95.2
TSS	300	72.6	75.8
COD	1000	200	80
Oil & Grease	53	—	—
Total Chrome	0.05	0.33	0
Phenol	0.24	0.33	0
Sulfide	0.20	0.67	0
pH (Units)	8	6 to 9	—

*Values are 30 day average - Maximum for any one day is twice the 30 day average.

Although oil and grease are not considered as a separate pollutant parameter required for 1977 limitations, it has been required by individual authorities for wastewater discharged to natural waters at limits of 10 to 30 mg/1. Emulsified oil in knit fabric finishing plants at high concentrations will interfere with the biological process and COD removals.

The model for treating wastewater containing high concentrations of emulsified oil capable of meeting 1977 effluent limitations is shown in Figure 7-5, which is the flow diagram for chemical treatment and air flotation followed by biological treatment. Physical treatment using the ultrafiltration technique to concentrate oil from its emulsified form may be another potential treatment method. It may be possible to produce a permeate which will contain less than 5 mg/1 oil and be reusable as process water. The concentrate (less than 10% by volume) may be dewatered further by the addition of a de-emulsifier and separation by air flotation. The concentrated oil has a potential use as a fuel for plant boilers. Long term problems with filtration membrane failure may be a major drawback in using this process.

Where emulsified oil concentration is lower than approximately 100 mg/1 and is not expected to present problems in a biological system, treatment using biological/chemical methods is suggested as shown in Figure 7-6.

7.6.1 Chemical Treatment/Air Flotation

Chemical coagulation using alum as a coagulant may be used to break the oil-in water emulsion. This method allows treatment of process and sanitary waste simultaneously.

7.6.1.1 Screening

An 80-mesh screen may be used to remove fiber, lint and solids before entering subsequent processes.

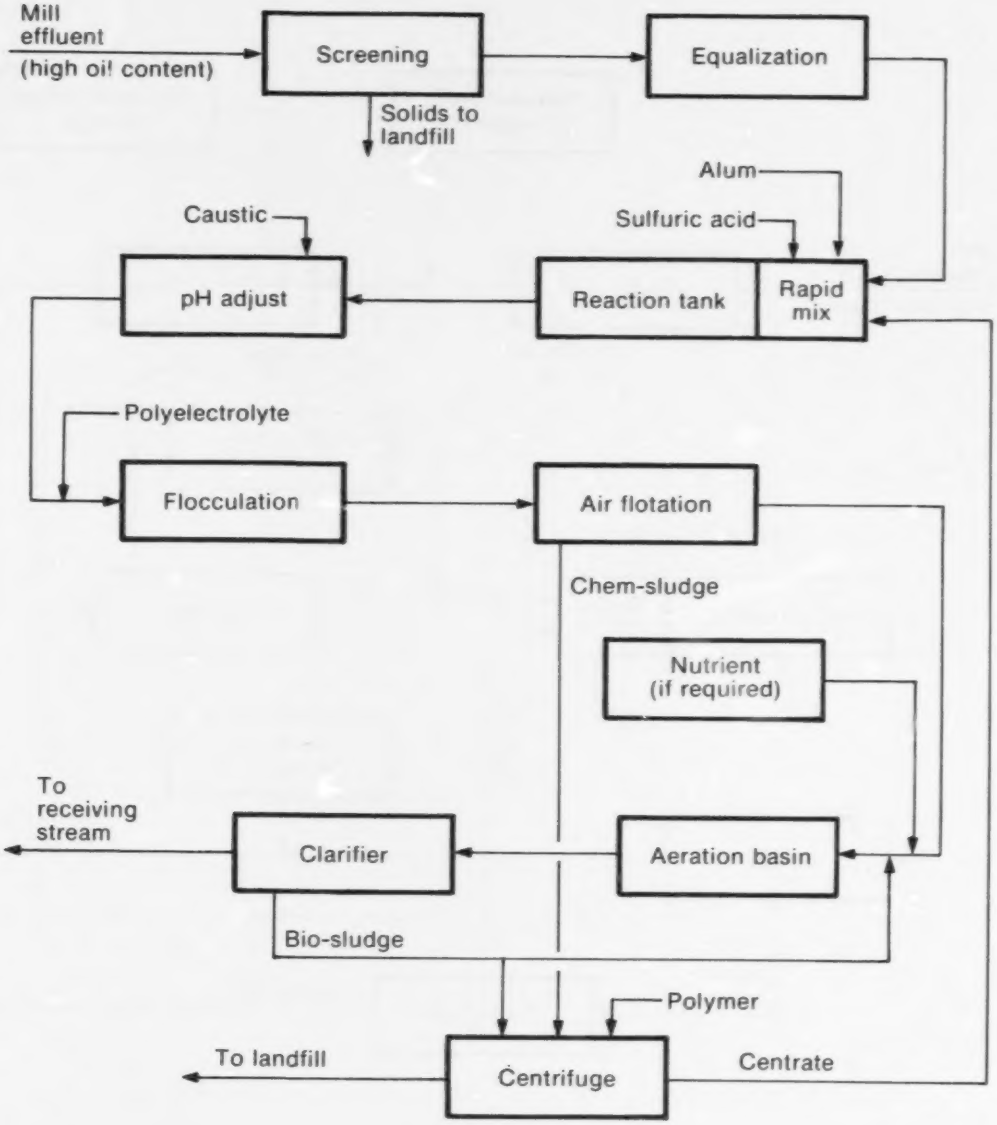
Mill effluent (high oil content)
Screening
Solids to landfill
Equalization
Alum
Sulfuric acid
Caustic
pH adjust
Reaction tank
Rapid mix
Polyelectrolyte
Flocculation
Air flotation
Chem-sludge
Nutrient (if required)
To receiving stream
Clarifier
Aeration basin
Bio-sludge
Polymer
To landfill
Centrifuge
Centrate

FIGURE 7-5

KNIT FABRIC FINISHING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

(High Oil Content)

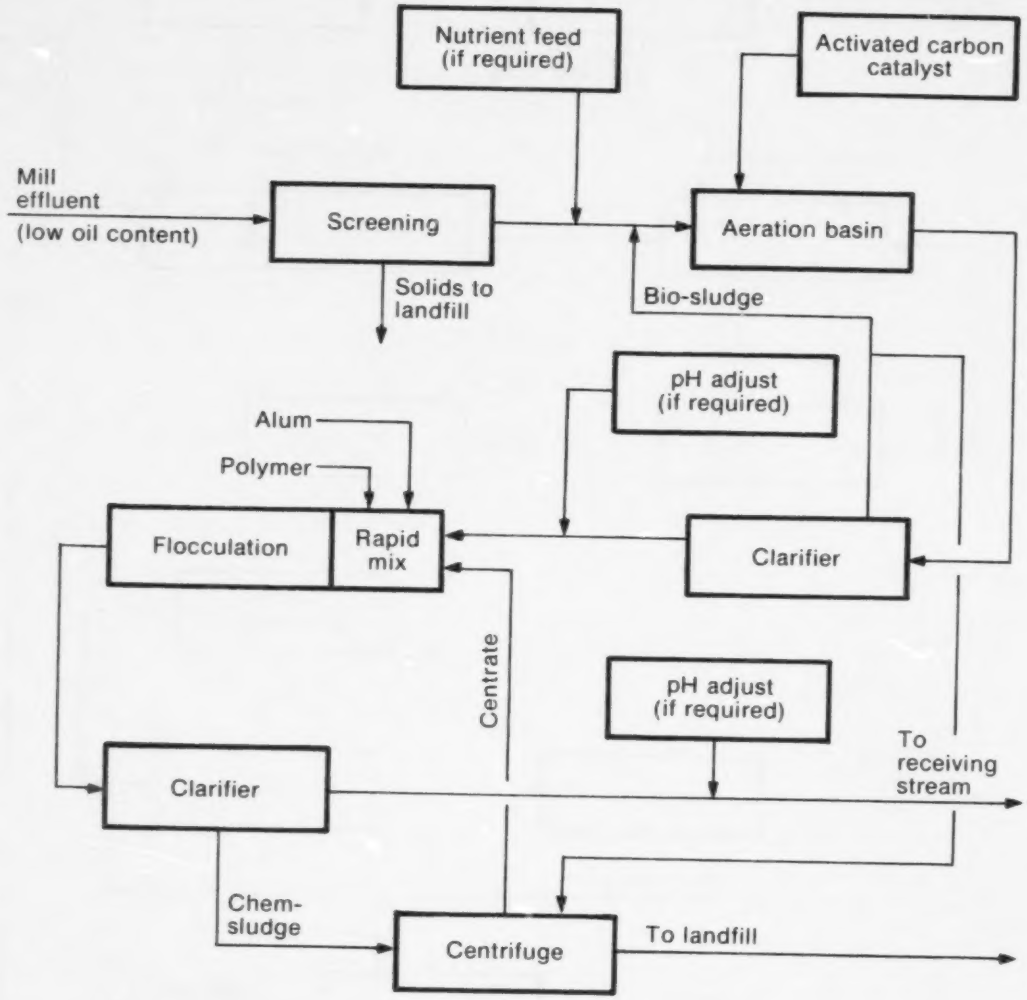
Nutrient feed (if required)
Activated carbon catalyst
Mill effluent (low oil content)
Screening
Aeration basin
Solids to landfill
Bio-sludge
pH adjust (if required)
Alum
Polymer
Flocculation
Rapid mix
Clarifier
Centrate
pH adjust (if required)
To receiving stream
Clarifier
Chem-sludge
Centrifuge
To landfill

FIGURE 7-6

KNIT FABRIC FINISHING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

(Low Oil Content)

7.6.1.2 Equalization

Equalization of mill effluent is desirable since chemical addition and pH adjustment are sensitive to waste characteristics. Adequate mixing should be provided in equalization to prevent septic conditions and solids deposition.

7.6.1.3 Chemical Treatment

Coagulation is accomplished by using alum and a polyelectrolyte. pH adjustment may be necessary to provide proper reaction between alum and emulsified oil. After forming the floc, the pH may have to be readjusted to meet effluent limits.

7.6.1.4 Flotation

Air flotation is used to separate the chemically coagulated floc. Flotation skimmings and settled sludge are further dewatered. Clarified effluent is introduced to the biological system.

7.6.1.5 Biological Treatment

Activated sludge extended aeration is used with 3 to 5 days retention time. Aqueous or anhydrous ammonia is added to serve as a nitrogen source. Sanitary sewage may also be used. Foaming problems are not anticipated unless a large percentage of fiber processed is cotton.

7.6.1.6 Sludge Treatment and Disposal

Centrifugation may be used for sludge dewatering of both chemical sludge and biological sludge. The sludges are fed separately to the centrifuge unit and are conditioned with a cationic polymer. The centrate is returned to the flocculation basin. Final disposal of sludge from the centrifuge is to a landfill. Other methods are available as illustrated in Chapter 8.

7.6.2 Physical Treatment Using Ultrafiltration Technique

Segregation of process effluent and sanitary wastewater is necessary to eliminate large solids to the system. Sanitary waste may be discharged to a package type plant or to a municipal sewer if available.

7.6.2.1 Screening

An 80-mesh screen is suitable to remove large particulates and fiber from the process effluent.

7.6.2.2 Equalization and pH Adjustment

Equalization is used to smooth the flow from batch dumps and to cool the effluent before pumping through the filter membrane. Adjustment of pH to a range of 5.5 to 7.5 is necessary to maintain proper operation of the ultrafiltration unit. Wastewaters from knit synthetic goods generally exhibit a pH within this range since only light scouring is needed. Knit cotton wastewaters usually have a high pH due to heavier scouring than is needed for knit snythetic goods and may require pH adjustment.

7.6.2.3 Ultrafiltration

Ultrafiltration may be used to separate the oil from the liquid waste. The system relies on the permeation of water through a semipermeable membrane under a hydraulic driving pressure (100 to 200 psi). Before entering the ultrafiltration modules, a 25 micron cartridge filter is used as a prefilter.

7.6.2.4 Flotation

Concentrate from the ultrafiltration unit is chemically de-emulsified. The mixture of oil and water is then separated by an air flotation unit. Underflow is recycled to the equilization basin.

7.6.3 Biological/Chemical Treatment

In the absence of excessive oil in the waste stream, biological treatment will operate effectively. However, in order to consistently meet the stringent removal efficiencies, chemical coagulation may be necessary for removal of remaining BOD, COD, and TSS.

7.6.3.1 Screening

Solids from knit fabric finishing such as natural fiber, lint, and short synthetic fiber are removed by fine screening. An 80-mesh screen is suitable for removing these solids.

7.6.3.2 Biological Treatment

An activated sludge system with 3-to-5 day retention time may be used to treat knit fabric finishing waste. Anhydrous or aqueous ammonia is added to serve as a nitrogen source in the aeration basin. In knit fabric finishing, the MLSS level may be found to be inadequate in the aeration basin. Powdered activated carbon is effective in bringing the MLSS level up. In addition, the carbon will increase efficiency in the aeration basin. Potential foaming from heavily scoured cotton knits would also be reduced by the carbon addition.

7.6.3.3 Chemical Treatment

Chemical coagulation and clarification will serve to reduce pollutants passing through the biological stage. Alum is used along with a polymer. Optimum treatment may require lowering the pH. If so, pH adjustment before discharging the effluent may also be necessary.

7.6.3.4 Sludge Dewatering

Biological and chemical sludges are dewatered separately by a horizontal solid bowl centrifuge. The centrate is returned to the rapid mixing basin.

7.6.3.5 Sludge Disposal

Centrifuged sludge is generally suitable for landfill.

7.7 Carpet Mill Wastewater Treatment

Carpet yarns in general use today include nylon, polyester, acrylic, modacrylic and wool. The dyeing of polyester and wool may generate phenols and chromium respectively. Process dye wastewaters are generally hot due to the lack of other wet processing steps in the mill. The high temperatures may present problems in biological treatment systems. Though knitting oils are not present in carpet yarn there may be traces of spinning oils.

TABLE 7-6
INTEGRATED CARPET MILL WASTEWATER PARAMETERS
(Point Source Category)

Parameters	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	300	56.3	81.2
TSS	120	79.3	33.8
COD	1000	507	49.3
Oil & Grease	—	—	—
Total Chrome	0.42	0.29	31
Phenol	0.13	0.29	0
Sulfide	0.14	0.58	0
pH (Units)	6 to 9	6 to 9	—

*Values are 30 day average - Maximum for any one day is twice 30 day average.

Figure 7-7 represents the flow diagram of a treatment facility capable of achieving the removal efficiencies necessary to meet 1977 regulations. This facility consists of latex segregation and settling, screening and biological treatment.

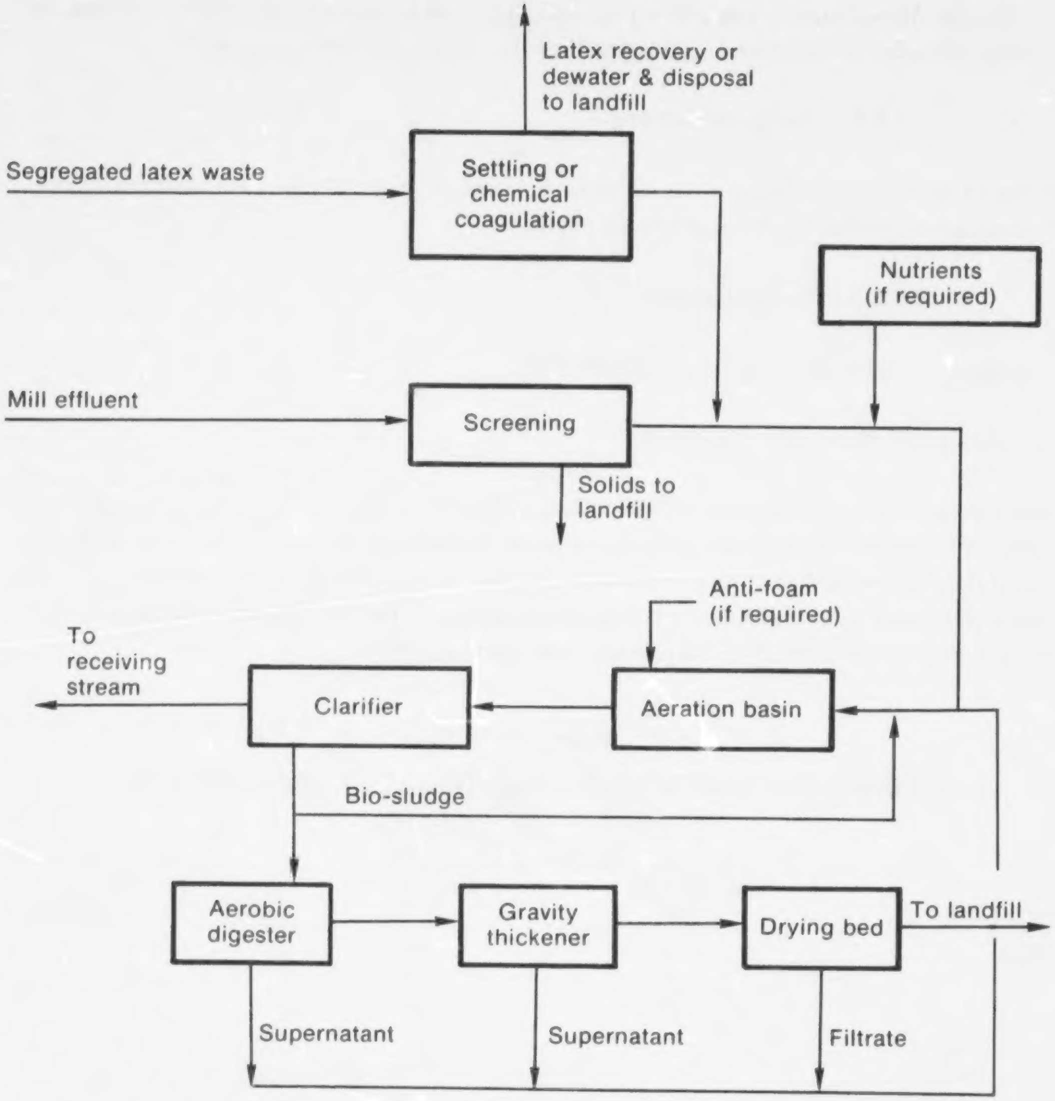
Latex recovery or
dewater & disposal
to landfill
Segregated latex waste
Settling or
chemical
coagulation
Nutrients
(if required)
Mill effluent
Screening
Solids to
landfill
Anti-foam
(if required)
To
receiving
stream
Clarifier
Aeration basin
Bio-sludge
Aerobic
digester
Gravity
thickener
Drying bed
To landfill
Supernatant
Supernatant
Filtrate

FIGURE 7-7

CARPET MILL WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

7.7.1 Latex Segregation

Latex wastewaters from backing operations are segregated and collected separately. The latex solids are settled in lagoons or are chemically coagulated and precipated. Sludge may be disposed of in a landfill; however, recent regulations governing such disposal must be complied with. The State of Georgia requires that latex sludge be "bladable" prior to landfill disposal. To meet this, a cake of approximately 55% solids may have to be produced using more extensive sludge dewatering methods.

7.7.2 Screening

Carpet mills discharge short fibers, strings, lint, fluffy yarns and small solids. If not removed, these materials impair subsequent biological treatment, particularly in low flow plants. These solids have been effectively separated using a hydraulically-cleaned sieve.

7.7.3 Biological Treatment

The activated sludge-extended aeration process may be selected for treating carpet mill wastewaters. Nutrient deficiency occurs in carpet wastes as it does in most textile wastes. Nitrogen as aqueous ammonia or anhydrous ammonia may be added to the waste as it enters the aeration basin.

Foaming problems are common due to latex foam in the backing process. Some mills experience foaming throughout the entire treatment facility. Conventional water sprays are not capable of effectively reducing the foaming. Anti-foam agents may be used to alleviate this problem. Though activated carbon may also be used to control foaming, its catalyst effects on biological treatment are not necessary to meet effluent limits.

7.7.4 Sludge Treatment and Disposal

Biological sludge is stabilized using aerobic digestion. This process has consistently demonstrated its value in the digestion of biological textile sludge. Supernatant from the digester is returned to the aeration basin. Digested sludge is thickened using a gravity thickener. Supernatant is also returned to the aeration basin.

Sludge disposal on open sand drying beds is common practice for many textile mills. A well digested sludge will result in optimum drying. Filtrate from drying beds is returned to the aeration basin, and dried sludge is hauled to a landfill. An alternative method of sludge disposal may be land application. Sludge at concentrations of 1.5 to 4% solids have been successfully sprayed onto the land. The system consists of pumps, distribution pipes and sprinkler heads.

7.8 Stock and Yarn Dyeing and Finishing Wastewater Treatment

Stock and yarn dyeing and finishing wastes are different from those of woven fabric finishing because there are no desizing operations performed. They are different from knit fabric finishing because there are no knitting oils to be scoured out before dyeing.

Wastewater characteristics in stock and yarn dyeing and finishing plants vary from plant to plant. Wastes generated depend substantially on whether natural fibers, blends or synthetics alone are processed.

When cotton thread is processed, mercerizing and heavy bleaching are required because of fiber impurities. Wastewaters generated are relatively high in BOD, detergent level, fiber impurities, dissolved solids, color, and pH. Because of the small amount involved, caustic soda recovery from mercerizing is generally not practiced. When synthetic yarn or raw stock is processed, mercerizing is not required, and only a light bleaching is performed. These wastewaters reflect lower BOD and dissolved solids.

Table 7-7 below represents average mill waste load characteristics, effluent limitations for point-source discharge, and required removal efficiencies for stock and yarn dyeing and finishing operations.

TABLE 7-7
STOCK AND YARN DYEING AND FINISHING WASTEWATER PARAMETERS
(Point Source Discharge)

Parameters	Mill Effluent mg/l	1977 Limit* mg/l	Percent Removal Required
BOD	250	22.6	91
TSS	75	58	22.7
COD	800	282	64.8
Oil & Grease	—	—	—
Total Chrome	0.27	0.4	0
Phenol	0.12	0.4	0
Sulfide	0.09	0.8	0
pH (Units)	11	6 to 9	—

*Values are 30 day average - Maximum for any one day is twice the 30 day average.

The flow diagram presented in Figure 7-8 represents a treatment facility capable of achieving removal efficiencies necessary to meet 1977 effluent limitations.

The treatment facility consists of screening, neutralization, and biological treatment. Sludge treatment involves aerobic digestion, gravity thickening, and disposal via drying beds and landfill or spray irrigation.

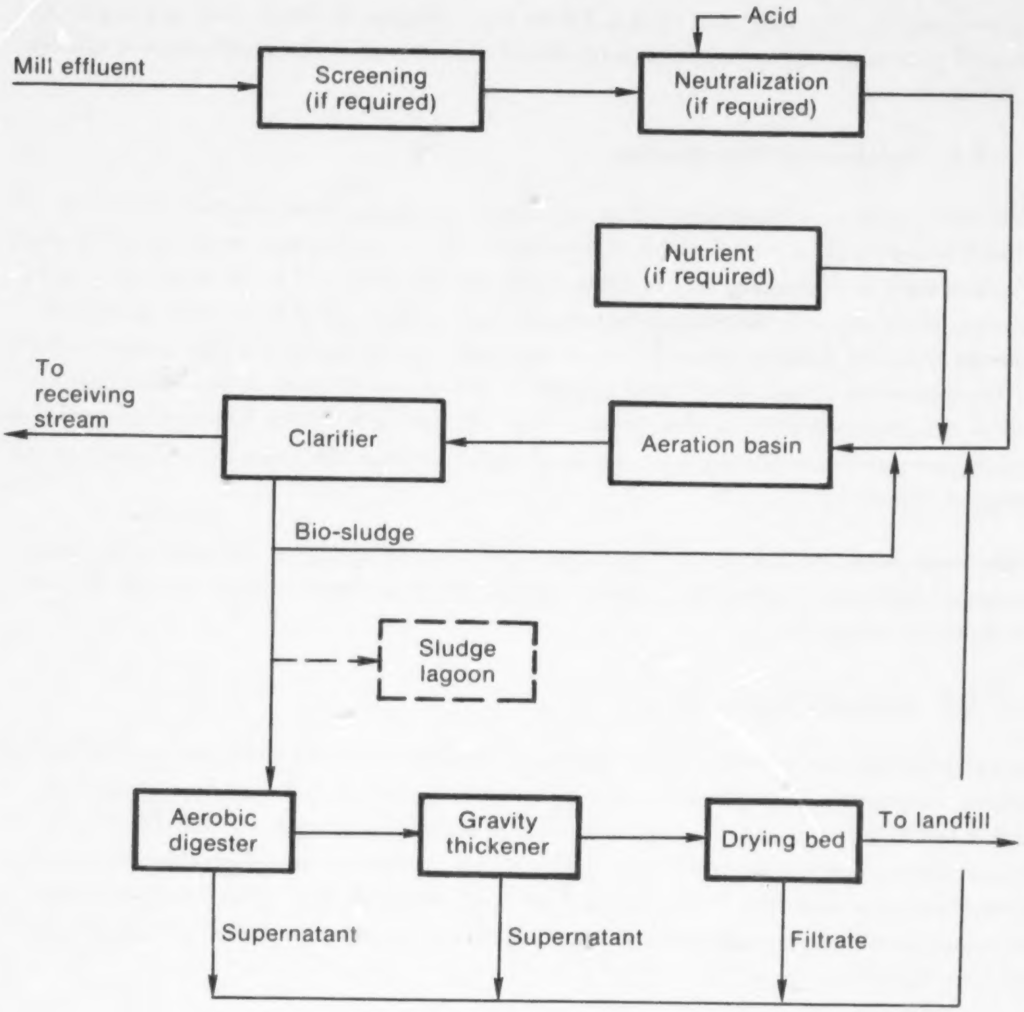
Acid
Mill effluent
Screening (if required)
Neutralization (if required)
Nutrient (if required)
To receiving stream
Clarifier
Aeration basin
Bio-sludge
Sludge lagoon
Aerobic digester
Gravity thickener
Drying bed
To landfill
Supernatant
Supernatant
Filtrate

FIGURE 7-8

STOCK AND YARN DYEING AND FINISHING WASTEWATER TREATMENT MODEL SCHEMATIC MEETING 1977 (BPT) LIMITATIONS

7.8.1 Screening

Stock and yarn dyeing and finishing mills generate very small amounts of suspended solids. These suspended solids are natural fiber impurities from bottom yarn and short fiber resulting from mercerizing, bleaching, and dyeing. Fibers cause clogging in the system and impair the biological process and, therefore, if present, should be removed. A fine mesh screen is suitable for this task.

7.8.2 Equalization/Neutralization

Equalization, with or without neutralization, may be necessary when wastewaters exhibit a widely fluctuating pH due to changing of yarn types. When cotton yarns are processed, sodium hydroxide used in mercerizing may result in a mill effluent with a pH in the range of 11 to 14. While raw stock or synthetic yarns do not require mercerizing, mill effluent pH is about 8.0. Although activated sludge systems can be operated with textile wastes at a high influent pH up to 10.5, the system is easily upset when changes of one or two pH units occur. Specialized bacteria are developed which acclimate to the high pH mill wastewaters. However, when changes occur in processed materials and when pH is affected, bacterial kills lower the efficiency of the biological process.

As discussed above, neutralization may be practiced ahead of biological activated sludge where dyeing and finishing of more than one yarn type are involved. Neutralization to a pH range of 7 to 8 should be adequate.

7.8.3 Biological Treatment

The extended aeration activated-sludge system is effective in treating stock and yarn dyeing and finishing wastewaters. Nitrogen deficiency is experienced in stock and yarn dyeing wastes as it is in other textile subcategories. Aqueous ammonia or anhydrous ammonia is added to serve as a nitrogen source. Color, though relatively high, will not interfere with biological treatment. The activated sludge process may be capable of removing better than 50% of the incoming color. Chromium content is generally low and, therefore, is not expected to present problems in biological treatment.

7.8.4 Treatment and Disposal

Sludge treatment may not be necessary since solids content is very low. Wasted sludge of small amounts from the activated sludge system can be treated in sludge lagoons. In cases where wasted sludge is a substantial amount, aerobic digestion is found suitable. Digested sludge may be thickened by a gravity thickener. Supernatant is returned to the aeration basin, and thickened sludge is dewatered before final disposal. Thickened sludge may be further dewatered by open drying beds. Sludge cake is then suitable for disposal to a landfill. Filtrate from the drying beds is returned to the aeration basin. An alternative disposal method is to pump thickened sludge to a spray irrigation site.

7.9 Color Removal

7.9.1 Wool Scouring Wastewater

Color from wool scouring is generated from impurities (dirt, blood, suint, etc.) in raw wool fiber and is likely to be reduced as a result of reduction in oil and grease and suspended solids.

7.9.2 Wool Finishing Wastewater

At the present time, most wool that is dyed is wool/polyester blends with very little 100% wool being dyed. The most common dyes used for wool and wool/polyester blends are acid and metallized dyes. Others used are mordant (chrome) dyes. Generally 100% wool cloth is dyed using metallized dyes which have a high affinity for wool and are considered fast.

Acid dyes are water soluble while disperse dyes are water insoluble. Acid dyes are responsive to activated carbon adsorption and lime coagulation. Disperse dyes are responsive to alum coagulation and respond reasonably well to lime coagulation; however, they are not responsive to activated carbon adsorption.

Chrome removal using copperas and lime will result in some color removal as well. The color removal is not significant since optimum pH for chrome reduction is 8.5 while that for color removal is 5.0. Additional color removal, if required, can be achieved by alum coagulation and activated carbon adsorption.

7.9.3 Dry Processing Wastewater

Color is not likely to be a problem for this category.

7.9.4 Woven and Knit Fabric Finishing Wastewater

The three most common dyes used in the dyeing process of 100% cotton woven or 100% cotton knit fabrics are direct, vat, and sulfur dyes. For cotton/synthetic blends, disperse dyes are commonly used in combination with direct, vat, or sulfur dyes. In processing 100% synthetic fibers, the most common dyes used are disperse, acid, and basic (also known as cationic) dyes. Additional dye types include developed, naphthol, and fiber reactive dyeing. It should be noted that most finishing plants use more than one class of dye thus complicating color removal.

Color removal for both woven and knit fabric finishing using direct dyeing would require physical treatment using activated carbon adsorption. Chemical coagulation cannot achieve satisfactory removal of soluble dyes, and biological treatment may not provide adequate color removal. Some of the direct dyes would have sufficient affinity for the sludge in a biological waste treatment plant to be absorbed and removed from the wastewater. Color removal by biological treatment could be improved by adding activated powdered carbon (as a catalyst) to the aeration basins of activated sludge systems. Of course, this treatment will not remove color as efficiently as adsorption in activated carbon columns; however, an additional color reduction of about 20 to 55% could be realized from this process. Experiments by Rodman of the Fram Corporation on color removal for direct dyes showed that in a catalyzed reactor when ammonia sulfate is used as a nutrient instead of ammonium chloride, better color removal will result. Biological treatment with powdered activated carbon appears feasible for treating woven finishing wastes where effluent limitations require approximately 80% color removal. Additional benefits of the use of powdered carbon would be the increase in efficiencies of BOD and COD removal and reduction in foaming problems.

In both woven and knit fabric finishing mills using vat dyes, color removal using alum coagulation may be accomplished following the biological process. The chemical process is capable of removing approximately 80% of the color. Optimum removals are achieved when the pH is adjusted to about 5.0 in the chemical coagulation process. If biodegradable dispersing agents are used in the commercially prepared vat dyes, the dispersion may be destroyed in biological treatment and the dye may be reduced by adsorption on the sludge. However, the pigment is fairly inert and therefore chemical coagulation by alum addition appears to be the best method for color removal.

In some cases where color removal requirements are more stringent than chemical coagulation can achieve, ozonation may provide the additional color removal necessary.

Color removal for woven and knit fabric using sulfur dyes may also be provided by chemical coagulation using alum as a coagulant and a polymer as a flocculant. Alum coagulation can remove up to 80% of the color. If color limits require additional removals, ozonation may provide the remaining reduction. Excess sulfide used in the dyeing process will be readily oxidized in the activated sludge system, and odor is not expected to be a problem if the pH is above 7.5.

Chemical coagulation using alum is excellent for color removal of disperse dye wastes while chemical coagulation using lime also produces good color removal. Disperse dye wastewaters are not responsive to color removal by activated carbon adsorption because their rate of adsorption onto carbon, like their rate of adsorption on textile fibers, is prohibitively long at room temperature. The rate of adsorption can be increased with heat, but heating is not usually feasible with most waste streams. Although disperse dye wastewater is not responsive to activated carbon adsorption, color removal is good in the activated sludge extended aeration system when activated carbon is used as a catalyst. Color removal of approximately 70% has been achieved in the catalyzed extended aeration process.

In woven and knit fabric finishing of 100% synthetic fibers using acid dyeing, the treatment process used to meet 1977 limitations will also result in some color removal. Acid dyes have good water solubility and are difficult to remove by the activated sludge process. Activated sludge may remove 30 to 40% of the color. In an activated sludge process with activated carbon as a catalyst, color removals of approximately 90% can be achieved. Activated carbon adsorption is an excellent method for color removal of acid dye waste. Experiments by Rodman (Textile Chemist and Colorist Nov. 11, 1971) showed that although acid dyes have good water solubility, chemical coagulation by lime produces excellent color removals for acid dyes wastes and that chemical coagulation by alum also produces good color removal.

Color removal for 100% synthetic woven and knit fabric finishing using basic dyes is accomplished to a great extent in activated sludge treatment. Activated carbon added as a catalyst will increase color removal. Additional color removal if required would necessitate activated carbon adsorption.

In knit fabric finishing mills where knitting oils are present in high levels and cause problems in biological treatment, both color removal and oil removal may be effectively accomplished using ultrafiltration. This process, though not considered established technology, has the potential for recycle of both the permeate (water) and concentrate (dyes).

7.9.5 Carpet Mill Wastewater

Acid dyes are the most common dyes used in carpet dyeing since nylon fiber is widely used as well as other synthetic fibers. Most wool used in carpets is dyed in yarn form with the use of acid dyes predominating. Other dyes used for carpets are disperse and small amounts of cationic.

Acid dyes are water soluble and may or may not be removed by the activated sludge process. Activated carbon adsorption is considered the best method for color removal. Ozonation has also been successful in reducing color from carpet mill wastewater effluents. See Chapter 8, Section 8.11.4 for details.

7.9.6 Stock and Yarn Dyeing and Finishing Wastewater

Dyes used for stock and yarn dyeing are similar to those used for woven and knit fabric finishing. Dye types will depend substantially on whether natural fibers, blends or synthetics are processed. Most common dyes used for stock and yarn dyeing are vat, direct, sulfur, disperse, acid and basic dyes. Some of this color may be removed by the activated sludge process. A reduction of approximately 30 to 44% is possible at a retention time of 3 to 4 days.

Direct, acid and basic dyes are water soluble. They are responsive to activated carbon adsorption. Adding activated carbon into the aeration basin as a catalyst will improve color removal in the activated sludge process. Acid dyes are also responsive to lime coagulation while direct dyes are not.

Vat, sulfur, and disperse dyes are insoluble dyes. They are responsive to alum coagulation. Disperse dyes are not responsive to activated carbon adsorption; however, adding activated carbon into an aeration basin as a catalyst will improve color removal in the activated sludge process. Additional color removal may be achieved by ozonation.

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CHAPTER 8

WASTEWATER TREATMENT FACILITIES DESIGN

8.1 Introduction

This Chapter is intended to be a practical guide, or aid, to be used with engineering judgment and experience in the design of textile wastewater treatment facilities.

The reader is reminded that the design parameters contained herein are intended only as a guide based upon past experiences. It is suggested that where possible laboratory treatability studies be conducted to determine most effective treatment methods and optimum parameters for full scale design. For detailed design techniques and calculations of industrial waste treatment units, the reader is referred to the following sources: References 1, 2, 3, and 4.

In meeting the objectives of the water pollution abatement program, it will be necessary for the textile industry to achieve very high percentage removals of pollutants; capital investments will naturally be substantial. It is for these reasons that the designer must utilize optimum design capabilities for all equipment used as part of the complete waste treatment system.

A qualified engineer can usually select a preferred treatment method from the available alternatives based upon accumulated data, past experience, and logic. Occasionally, two systems or process units will appear so nearly comparable that it is difficult to make a decision. Cost estimates can usually resolve this problem. Capital, operating, and maintenance cost estimates are evaluated as part of the decision making process. The subject of unit cost, both capital and O&M, has been detailed by a number of publications to which the reader is referred as follows: Reference 5, 6, 7, 8, and 9. These publications generally provide graphical relationships between cost (capital, annual) and size (flow, production).

In addition, consideration for future expansion or upgrading of facilities cannot be overemphasized. Much can be gained by preplanning and incorporation of adequate space, capacity, and durability for the future into today's designs.

8.2 Basic Design Considerations

8.2.1 In-Plant Changes

Changes in plant processes or chemicals used will affect waste effluent quantity and quality. Consideration should be given to planned changes and their potential effect.

8.2.2 Degree of Treatment Required

Initial design is based upon meeting EPA point source limits using best practicable control technology (BPT). However, special consideration must be given for the more stringent water quality limited situation and, of course, for pretreatment before discharge to municipal systems.

8.2.3 Anticipated Treatment Efficiencies

The ability of a particular unit process to remove pollutants is dependent upon specific effluent wastewater characteristics. Table 8-1 illustrates a range of treatment removal efficiencies generally attainable with textile wastewaters.

TABLE 8-1
ANTICIPATED TREATMENT REMOVAL EFFICIENCIES

Treatment Unit Process	Range of Removal Efficiency in Percent				
	BOD_5	COD	TSS	Grease	Color
Primary Treatment					
Screening	0-5	—	5-20	—	—
Equalization	0-20	—	—	—	—
Neutralization	—	—	—	—	—
Chemical Coagulation (removals vary with chemicals and dosage used)	40-70	40-70	30-90	90-97	0-70
Flotation	30-50	20-40	50-60	90-98	—
Secondary Treatment					
Conventional Activated Sludge and Clarification	70-95+	50-70	85-95	0-15	Color removals for biological treatment units not documented
Extended Aeration and Clarification	70-94+	50-70	85-95	0-15	
Aerated Lagoon and Clarification	60-90	45-60	85-95	0-10	
Aerobic Lagoon	50-80	35-60	50-80	0-10	
Packed Tower	40-70	20-40	—	—	
Roughing Filter	40-60	20-30	—	—	
Tertiary Treatment					
Chemical Coagulation	40-70	40-70	30-90	90-97	0-70
Mixed Media Filtration	25-40	25-40	80	—	—
Carbon Adsorption	25-40	25-60	25-40	—	80-90
Chlorination	0-5	0-5	—	0-5	0-5
Ozonation	—	30-40	50-70	—	70-80
Advanced Treatment					
Spray Irrigation	90-95	80-90	95-98	—	—
Evaporation	98-99	95-98	99	—	—
Reverse Osmosis	95-99	90-95	95-98	—	—

Source: National Commission on Water Quality, Textile Industry Technology and Costs of Wastewater Control, Lockwood Greene Engineers, Inc., June 1975.

8.2.4 Design Period

It is usual practice to design treatment facilities for a 15- to 25-year life span.

8.2.5 Future Expansion

Anticipated manufacturing plant expansion should be considered in terms of sizing wastewater conduits, structures and equipment for the most economical accommodation of future waste loads.

8.2.6 Seasonal Considerations

It is possible that manufactured goods will change, depending upon the season of the year. Of course, in the textile industry, this change is more directly related to market demands (fashions) and is almost impossible to predict, e.g., the surge in the use of denim.

Another seasonal consideration is that of climate. Ambient temperatures have a definite effect on biological treatment processes as well as on the operation of mechanical equipment.

8.2.7 Costs

In our cost-conscious society, it behooves the design engineer to investigate the most economical construction methods and materials available to accomplish the abatement project; e.g., the use of earthen lagoons and, where possible, locally available materials.

8.2.8 Degree of Automation

It is important at the onset of the project that the design engineer determine from the client the extent of automation he wishes built into the treatment facility. Automation has the potential for reducing otherwise necessary labor costs as well as reducing chemical wastage.

8.2.9 Sludge Disposal Methods

The decision making for sludge disposal will depend heavily upon economics. There are, however, other considerations such as ultimate disposal regulations, availability of landfill, and potential markets such as agricultural uses or energy sources.

8.2.10 Multiple Units and Emergency Power

It is the practice of most regulatory agencies to require continuous operation of the treatment facilities with the largest unit out of service with essentially no change in the degree of treatment. Emergency storage alone may be adequate for industrial facilities.

Standby power is required by most agencies for municipal facilities. It is not expected that standby power is required for industrial facilities, unless the manufacturing plant is so equipped to maintain operation during periods of primary power failure.

It should be recognized, however, that a biological treatment facility without power for feeding raw waste or providing oxygen, for an extended period of time, may result in a kill of microorganisms.

8.2.11 Design Standards

A recent survey of most state environmental agencies in the U.S. revealed that none have formal design standards which relate to textile manufacturing. In fact, with regard to industrial facilities most states review design requirements on a case-by-case basis. As a guide, many states utilize established criteria such as those created by the Ten States and New England Interstate Water Pollution Control Commission (10), (11). These works are based upon municipal facilities treating domestic wastes. Some states have written their own set of design standards for sewage works; however, many of these are also based upon the most popular Ten States.

Though commonly known as the Ten States Standards, these standards were created by a committee of the Great Lakes – Upper Mississippi River Board of State Sanitary Engineers. Member states include the following: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania and Wisconsin. The intent of these standards is contained in the foreword of the 1971 revised edition and reads as follows:

> These standards are intended for use as a guide in the design and preparation of plans and specifications for sewage works; to list and suggest limiting values for items upon which an evaluation of such plans and specifications will be made by the reviewing authority; and to establish, as far as practicable, uniformity of practice among the several states. Statutory requirements among the states are not uniform and use of the standard must adjust itself to these variations.

The design section of this chapter will present excerpts of design considerations from the Ten States or New England standards considered applicable to textile wastewater treatment.

8.3 Site Requirements

8.3.1 Topography

Site selections will depend very heavily upon topography of the area under consideration. The terrain will determine the ability to utilize gravity flow or the need for pumping facilities. Costs will be affected by power for pumping facilities and during construction by the amounts of cut and fill required.

8.3.2 Buffer Zone

Affecting site selection will be local zoning restrictions and the requirements for buffer areas. Distances to nearest habitable and adjoining property owners are set by some states while other states review on a case-by-case basis. Following are examples of minimum distances set:

Treatment Units – 150 ft. from habitable property lines
– 300 ft. from residences
Spray Irrigation Sites – 200 ft., preferably wooded

8.3.3 Flood Plains

Most regulations require that if any portion of the facilities will be subject to upland or tidal flooding, the engineer must discuss the extent and effects of such flooding with the agency. Precautions against flooding will usually be required to be incorporated into the design.

8.3.4 Subsurface Groundwater

The existence of a high groundwater table on the plant site can cause difficulties. There is the problem of below ground construction as well as the potential for groundwater contamination from spills and leaks.

8.3.5 Soil Conditions

Subsurface soil bearing loads and the existence of rock will seriously affect foundation requirements and construction methods to be employed. Soil boring tests should be performed.

8.3.6 Existing Facilities

The location of existing facilities and the capacity to deliver necessary power, chemicals, water, etc. is an item of concern related to construction cost as well as operating cost.

8.3.7 Receiving Stream

It is important to know the capacity and quality of receiving waters as water quality effluent limitations may be more stringent than EPA guidelines.

8.3.8 Future Expansion

Associated with site selection is the consideration for expanding the proposed facilities, either by enlarging existing units or providing additional units. The site should be flexible and allow for future expansion without disrupting present operations.

8.3.9 Miscellaneous

Good design practices also suggest the need for providing the following at selected sites:

- Access Roads
- Walkways
- Area Lighting
- Fencing
- Warning Signs

8.4 Sewers and Pumps

8.4.1 Gravity Sewers

A sewer has two main functions: 1) To carry the maximum discharge for which it is designed; and, 2) to transport suspended solids without their deposition into the pipe. The first function requires that an estimate be made of the peak flow which the sewer must carry; and the second requires that the designer have information as to the fluctuation of discharge during periods of low flow and as to the character of the suspended matter to be transported.

In terms of pipe materials, sewers may be vitrified clay, cast iron, or concrete to name a few. Cast iron is generally the preferred choice because though more expensive it can be used underground without fear of leaks or breakage. Vitrified clay may also be considered a good choice because of its resistance to varying pH of textile waste and because of its lower costs. Trench load will also have a bearing on pipe selection.

In the design of sewers, the following considerations are given by the Ten States Standards:

- Design for mean velocities, when flowing full, of not less than 2.0 feet per second, based on Kutter's formula using an "n" value of 0.013.
- Sewers to be laid with uniform slope between manholes.
- Avoid velocities greater than 15 feet per second.
- Manhole required every 400 feet for sewer 15 inches diameter or less and 500 feet for sewers 18 to 30 inches diameter.
- Drop type manhole required for sewer entering manhole 24 inches or more above manhole invert.

8.4.2 Centrifugal Pumps

In general, most textile mill effluents can be pumped by centrifugal pumps. This classification includes radial flow, axial flow and mixed flow types. Pump impellers may be closed, semiopen or open. Radial flow pumps are manufactured as horizontal or vertical while axial or mixed flow are constructed vertically.

Centrifugal pumps should be avoided for applications with very viscous liquids, high solids content or low flows with high heads.

8.4.3 Positive Displacement Pumps

Included in this classification are piston, plunger and diaphragm type pumps. These pumps are used to feed metered quantities of chemicals and also to pump waste sludge. Suction and discharge valves used are commonly ball-type.

8.4.4 Rotary Screw Pumps

This type of pump is commonly used to transfer sludge. The progressing cavity rotary pump is suitable for handling heavy concentrated sludge.

8.4.5 Air Pumps

These are specialized pumps such as the pneumatic ejector or air-lift pump. The pneumatic ejector is used when quantities of waste are small and future increase in flow is limited. An advantage of this type of pump is its lack of moving parts in contact with the waste, therefore, less tendency to clog. Air-lift pumps are suited to the transfer of mixed liquors or slurries. Flow rates can be high for short distances.

8.4.6 Pumping Stations

Pumping stations are generally either of the dry well type or the wet well type. Prefabricated package type stations are available to meet the needs of the largest textile treatment uses. The Ten State Standards, though written for domestic wastes, presents some important considerations in the design of pumping stations:

- Protect pumps from clogging by use of bar racks or screens.
- Make provisions for removing pumps and motors.
- Provide duplicate pumps of equal capacity.
- Provide automatic controls and automatically alternate pumps in use.
- Activate an alarm in case of pump failure.
- Adequate ventilation should be provided.

8.5 Suspended Solids Removal

Suspended solids include both organic and inorganic materials. The inorganic components include sand, silt, and clay. The organic portion may include grease, oil, tar, animal fats, fibers, hair and various other materials.

Methods most frequently employed for liquid-solids separation include: Screening, sedimentation (clarification), filtration and flotation. The following sections will present design parameters for methods most often associated with the removal of suspended solids in textile wastewaters.

8.5.1 Screening and Comminution

The primary purpose of screening is to prevent clogging of pipes and equipment and to avoid entrance of fibers and debris into successive treatment units. Clogging is generally caused by rags, strings or individual fibers of 1 to 2 inches which gather together to form balls or mats. Fibers which pass through an aeration basin may rise to the surface of settling basins to form mats or scum and may pass through into the final effluent resulting in an increased suspended solids concentration. Comminutors are generally required only for shredding the larger solids and rags associated with the sanitary portion of the plant wastewaters. See Figure 8-1. Textile waste solids are best handled using one of a number of screening devices available. The type of screening equipment used will depend upon the fiber size, concentration, subsequent treatment processes, allowable suspended solids concentration and relative operation and maintenance costs. If careful in-plant control is used, only a simple bar screen or rack may be required; however, if a large amount of fibrous material is present, a fine screen will be necessary. A bar screen or rack may be either hand or mechanically cleaned, (see Figure 8-2 and 8-3).

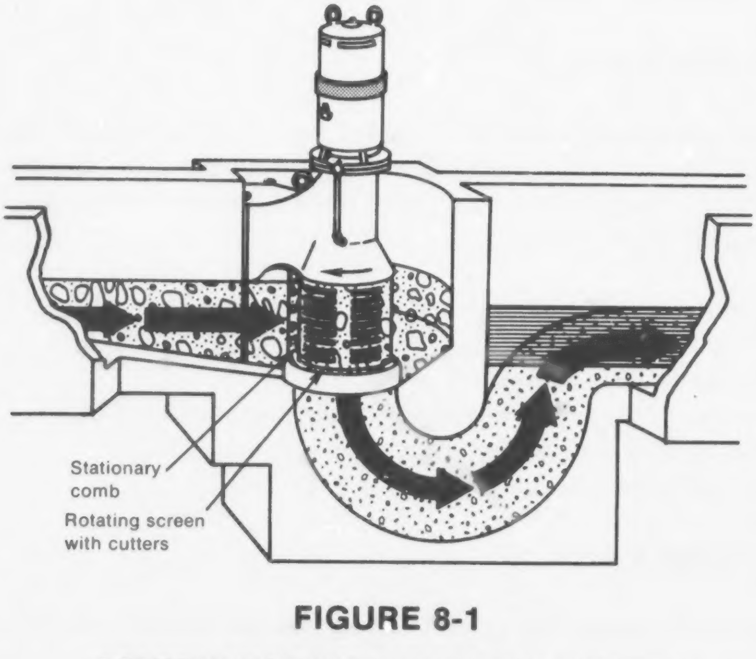
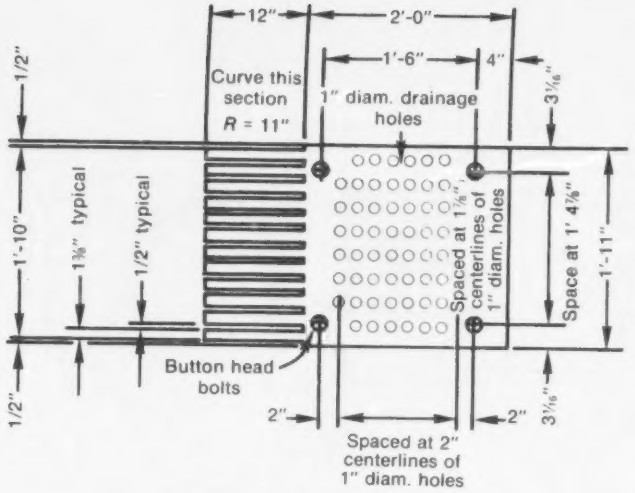


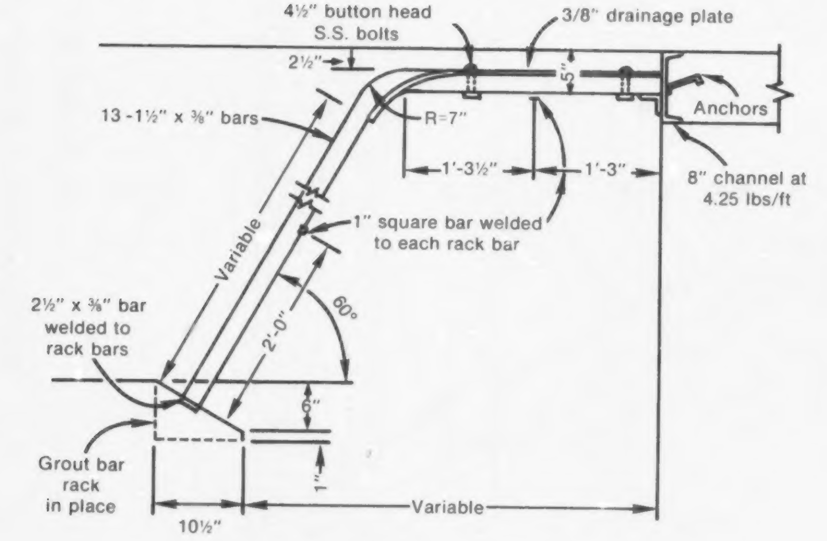
FIGURE 8-1

COMMINUTOR WITH ROTATING SCREEN

Source: Environmental Engineer's Handbook


12"
2'-0"
1'-6"
4"
1/2"
3 1/16"
Curve this section R = 11"
1" diam. drainage holes
1'-10"
1⅜" typical
1/2" typical
Spaced at 1⅞" centerlines of 1" diam. holes
Space at 1' 4⅞"
1'-11"
Button head bolts
1/2"
2"
2"
3 1/16"
Spaced at 2" centerlines of 1" diam. holes

DRAINAGE PLATE PLAN

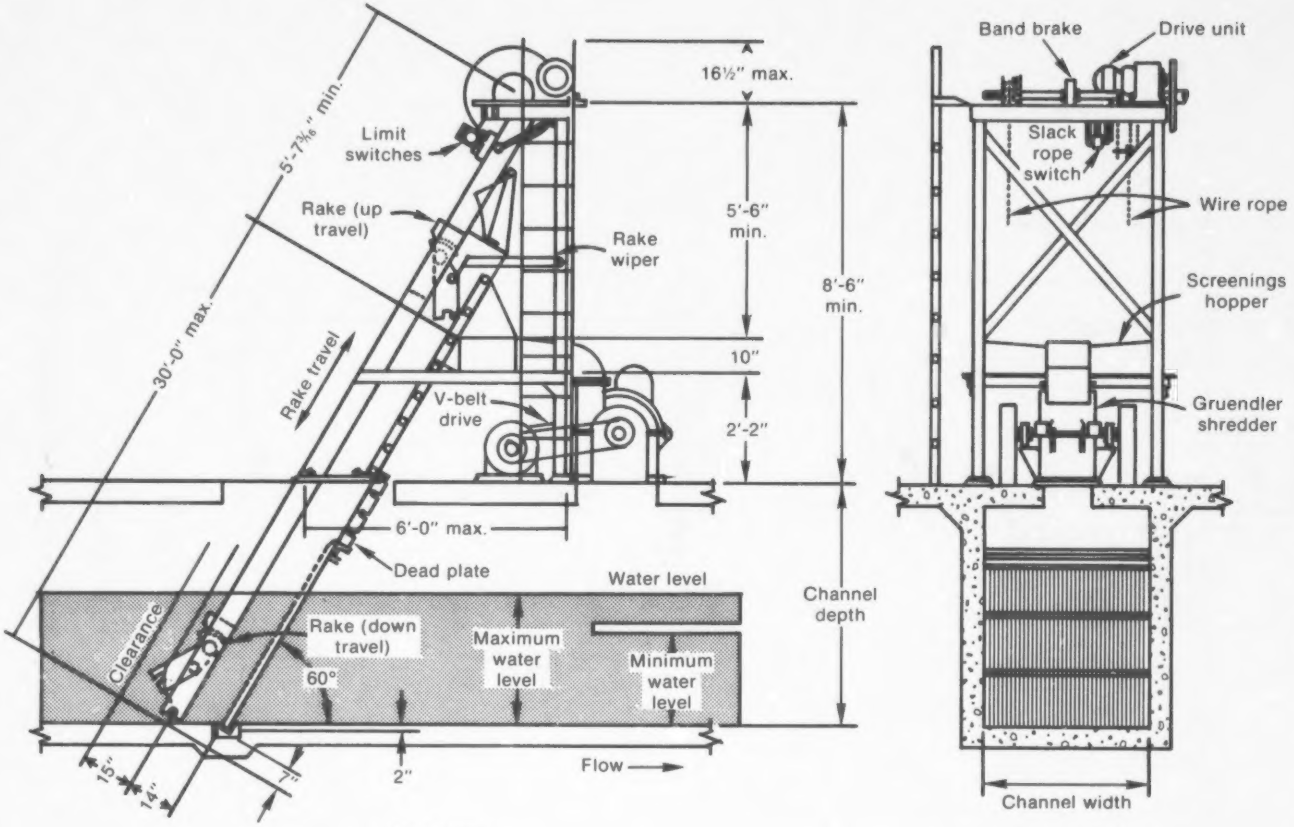

4½" button head S.S. bolts
3/8" drainage plate
2½"
5"
13 -1½" x ⅜" bars
R=7"
Anchors
1'-3½"
1'-3"
8" channel at 4.25 lbs/ft
1" square bar welded to each rack bar
Variable
60°
2½" x ⅜" bar welded to rack bars
2'-0"
6"
Grout bar rack in place
1"
10½"
Variable

RACK DETAILS

FIGURE 8-2

HAND CLEANED BAR RACK

Source: Metcalf & Eddy, Wastewater Engineering: Collection, Treatment, Disposal


5'-7³⁄₁₆" min.
30'-0" max.
Limit switches
Rake (up travel)
Rake travel
Rake wiper
V-belt drive
16½" max.
5'-6" min.
10"
2'-2"
8'-6" min.
6'-0" max.
Dead plate
Water level
Channel depth
Clearance
Rake (down travel)
60°
Maximum water level
Minimum water level
15"
14"
7"
2"
Flow
Band brake
Drive unit
Slack rope switch
Wire rope
Screenings hopper
Gruendler shredder
Channel width

SIDE VIEW

REAR VIEW

FIGURE 8-3

MECHANICALLY CLEANED BAR RACK

Source: Metcalf & Eddy, Wastewater Resources

Fine screens utilize varied methods for solids removal. A description of a number of those used at textile mills follows:

8.5.1.1 Vibrating Screens

Removal of materials with the vibrating screen is accomplished by an eccentric rotating weight which causes the screen to vibrate in an orbital pattern forcing solids to roll to the perimeter where they are collected (see Figure 8-4). Vibration reduces the blinding and clogging of the fine screens. To further reduce clogging, the screen may be equipped with spray washers or steam jets.

8.5.1.2 Hydrasieve

Hydraulically-cleaned screens use a jet of water to propel the waste against a series of tiny bars that allow the water to pass over while the solids are retained and washed to the bottom of the screen for collection.

Wastewater is fed by gravity to the screen from a headbox. There are no moving parts and the screen is self-cleaning (see Figure 8-5).

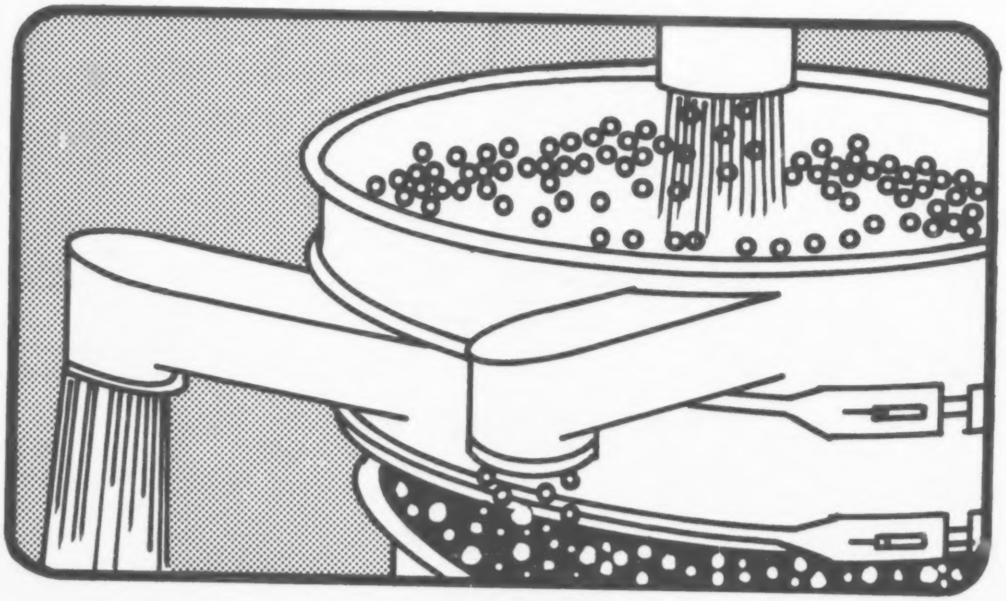
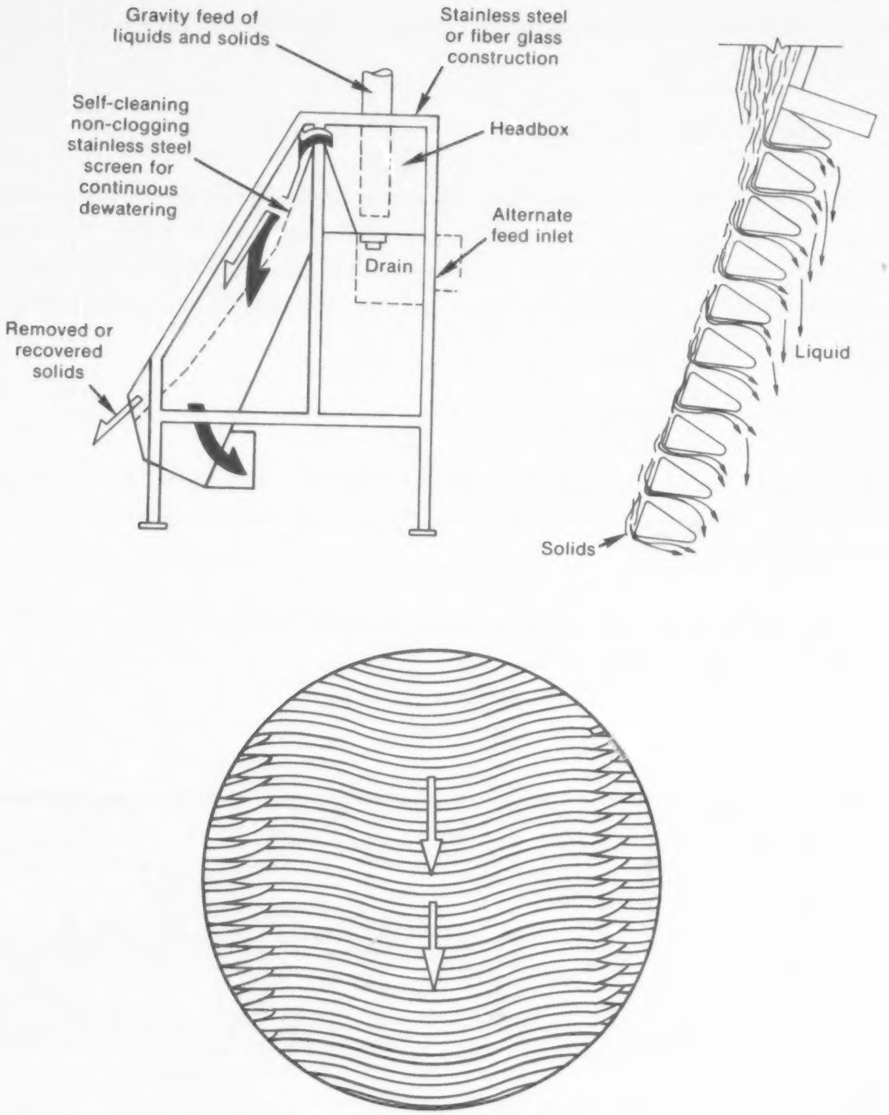


FIGURE 8-4

VIBRATING SCREEN


Gravity feed of liquids and solids
Stainless steel or fiber glass construction
Self-cleaning non-clogging stainless steel screen for continuous dewatering
Headbox
Alternate feed inlet
Drain
Removed or recovered solids
Liquid
Solids

ENLARGED SECTION OF THE SCREEN

FIGURE 8-5

HYDRASIEVE

Source: Environmental Engineer's Handbook

8.5.1.3 Rotating Drum Screen

Removal of materials is accomplished by a screen applied to a cylindrical frame which rotates while being 1/2 to 2/3 submerged. Solids are retained on the inside or outside of the screen (depending upon inward or outward flow) and are removed by water sprays, scrapers or brushes when rotated above the liquid level (see Figure 8-6).

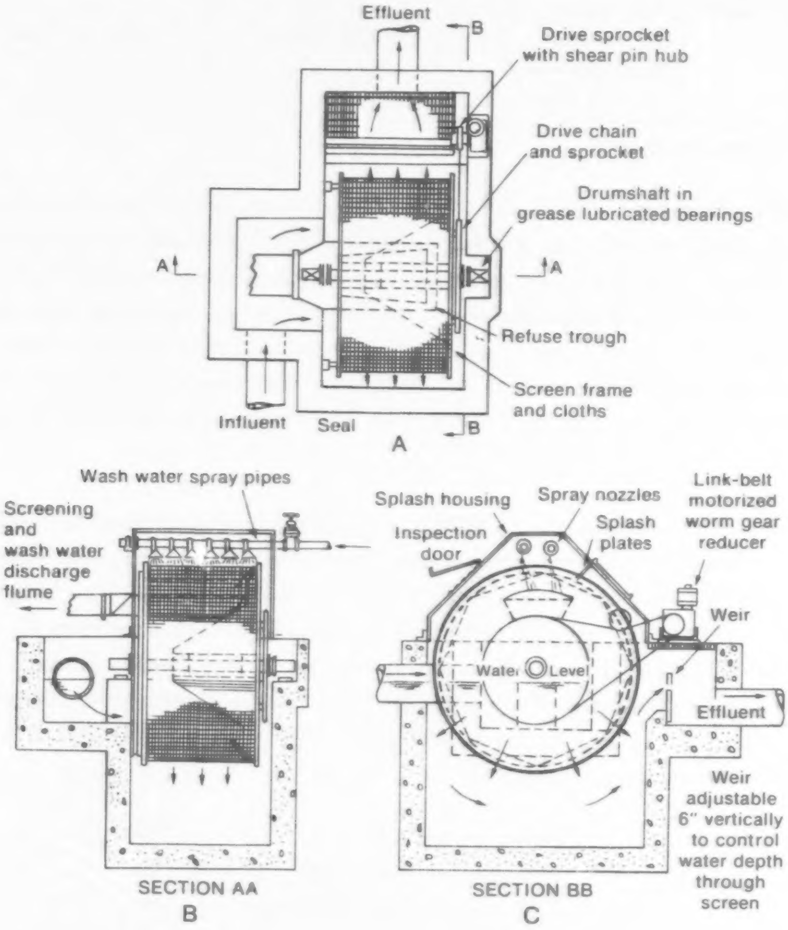

Effluent
B
Drive sprocket with shear pin hub
Drive chain and sprocket
Drumshaft in grease lubricated bearings
A
A
Refuse trough
Screen frame and cloths
Influent
Seal
B
A
Wash water spray pipes
Screening and wash water discharge flume
SECTION AA
B
Splash housing
Spray nozzles
Splash plates
Link-belt motorized worm gear reducer
Inspection door
Weir
Water Level
Effluent
Weir adjustable 6" vertically to control water depth through screen
SECTION BB
C

FIGURE 8-6

REVOLVING DRUM SCREEN

Source: Environmental Engineer's Handbook

Following is a tabulation of screen types and factors used in design and installation of each:

TABLE 8-2
DESIGN PARAMETERS FOR SCREENS

Screen Type	Spacing	Slope	Velocity
Trash Rack	2" to 6"	30° to 45°	—
Manually Cleaned	1" to 2"	30° to 45°	2.0 fps. Max.
Mechanically Cleaned	5/8" to 1"	—	—
Hydrasieve	.02" to .03"	25°, 35°, & 45°	Gravity Flow
Fine Mesh	40 to 80 mesh*	None	—
Comminutor	>1/4" slots	90°	—

*Mesh size can be obtained in the field

Whenever possible, thorough field or pilot testing of equipment is recommended. Most larger equipment manufacturers have pilot facilities available for such purposes. It should be noted that "highly efficient" screening might mean removal of only 10% of the total filterable solids. One might argue logically that lagooning would probably be cheaper and more effective, but this method also removes some organic material that can lead to objectionable odors. Also, extended cloudy periods tend to increase the possibility of carry-overs which could upset subsequent treatment. Other possibilities for fiber removal include simple sand beds or automated sand filters.

Design flow rates are best determined by field testing. One such test revealed that 900 gpm is the optimum for a 60-inch vibrating screen. Lower flows increase blinding while higher flows reduce removal efficiency. Mesh sizes of 40 to 80 may be suitable for removal of lint, but actual practice has shown 40-mesh screens, in particular, to be inadequate in some cases for this task. A carpet mill, for example, will discharge longer fibrous waste than would a package dye plant processing short staple spun yarns. A 40-mesh screen would be appropriate for the carpet; 80-mesh for the package dyer (12). One manufacturer of a high-speed vibrating screen makes the following mesh size recommendations (13):

Wool wash water	– 40
Mercerizing wash water	– 80
Cotton towelling wash water	– 60

To aid in the detailed design and installation of screening facilities, the following are considered widely adopted standards:

- Deep pits containing screens shall be provided with stairway access, adequate lighting and ventilation, and convenient and adequate means for removing screenings.

- Screening devices installed in a building where other equipment or offices are located should be separated from the rest of the building, provided with separate outside entrances, and provided with adequate means of ventilation.

- Manually Cleaned Screens: Clear openings between bars should be 1¼ to 2 inches. Design and installation of bar screens shall be such that they can be conveniently cleaned. Hand-cleaned screens should be placed on a slope of 30 to 45 degrees with the horizontal.

- Comminuting devices shall have slots not less than 1/4 inch wide and be designed to shred material below the surface of the wastewater. Comminutor capacitor shall be adequate to handle peak flows.

- A by-pass screen shall be provided except where there are multiple units. Where a by-pass screen is utilized, the overflow to the by-pass channel should occur when the influent channel is flowing at a depth which corresponds to the design flow through the comminutor. The overflow to the by-pass screen should be automatic so as to prevent flooding caused by clogging of the comminutor.

- Velocities: Screen chambers should be designed to provide a good velocity distribution across and through the screen of approximately two feet per second at average rate of flow. The velocity shall be calculated from a vertical projection of the screen openings on the cross-sectional area between the invert of the channel and the flow line.

- Channels: The channel preceding and following the screens shall be shaped to eliminate standing and settling of solids. Fillets may be necessary.

- All mechanical units which are operated by timing devices should be provided with auxiliary controls which will set the cleaning mechanism in operation at predetermined high water marks.

- Screenings: Adequate facilities must be provided for removal, handling, storage, and disposal of screenings.

- Auxiliary Screens: Where mechanically operated screening or comminuting devices are used, axuiliary hand-cleaned screens shall be provided. Design shall include provision for automatic diversion of the entire wastewater flow through the auxiliary screens should the mechanical units fail.

- Fine Screens: The use of fine screens may be required in special cases where the features peculiar to this equipment may be used to advantage.

8.5.2 Clarification

Clarification, also termed sedimentation, uses the force of gravity to remove settleable solids from wastewaters. Sedimentation is one of the simplest and most widely employed waste treatment processes. Sedimentation is usually used for BOD and settleable-solids removal. Primary sedimentation is usually omitted in most textile waste treatment plants due to low settleable solids levels. However, the settling basin may be a useful site for other pretreatment, when it is available, and may be part of the pretreatment system. It may be used for partial equalization, fiber removal, scum removal, pH regulations, chromium removal, chemical coagulation, sulfide treatment, and phenolic treatment. Usually, the tank is sized to provide a 3-hour detention, and scum and settleable-solids removal are mechanically accomplished. Chemical coagulation at this point may aid in reducing the insoluble BOD loads to the treatment plant. An idealized sedimentation basin is shown in Figure 8-7 (14). The basin is divided into four zones; inlet, outlet, settling, and sludge. The inlet zone must dissipate the kinetic energy of the feed stream and provide a uniform distribution of the flow entering the settling zone without creating excessive turbulence. The relative importance of proper inlet conditions as compared to outlet conditions has been shown. The outlet zone is less critical to basin performance, but low approach velocities to effluent weirs must be maintained for maximum sedimentation efficiency. The difficulties in obtaining optimum inlet and outlet conditions vary with basin shape and flow patterns.

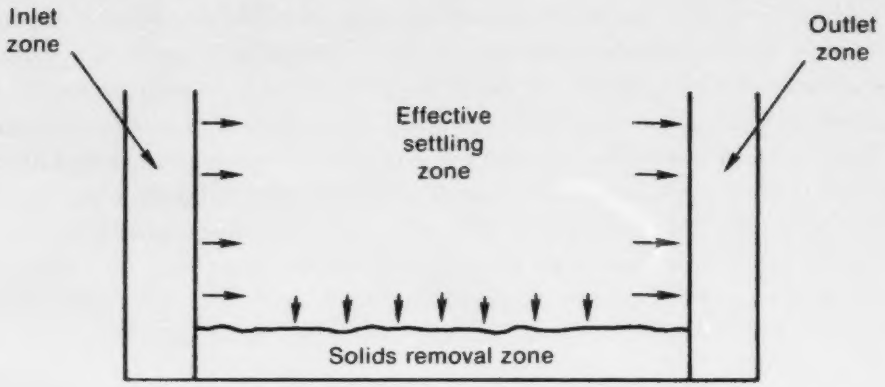
The idealized rectangular basin shown in Figure 8-7 illustrates the situation which occurs when a perfect inlet distribution of discrete particles occurs with no particle interaction and no resuspension of particles from the sludge zone. The resultant vector on the discrete particle is then made up of its theoretical settling velocity, usually described by Stokes' Law, and the superficial uniform velocity of the liquid.

In reality, uniform flow has been unattainable in the large tanks normally designed. Short-circuited turbulence and density currents have been cited as causing the major deviations from the ideal situation.

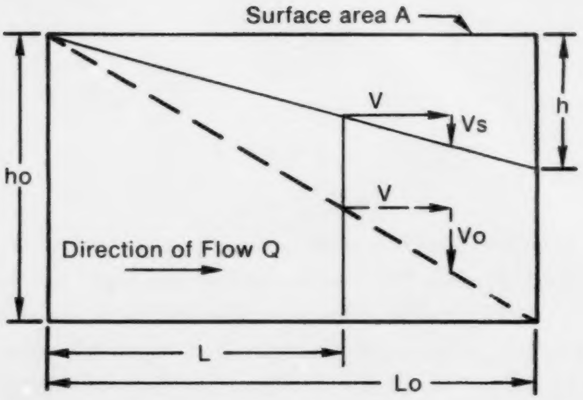
The sludge zone serves the two-fold function of retaining the solids so that a minimum of resuspension occurs and providing sufficient time for compaction, thereby minimizing sludge pumping requirements. In most cases, mechanical scrapers are utilized to move the sludge slowly to the pump draw-off area. An alternative device uses suction to remove the sludge at its deposition point, thereby eliminating the need for displacement prior to removal.

8.5.2.1 Primary Sedimentation

Primary clarifiers are designed to remove the settleable solids and their associated organic load from the wastewater. Textile wastewaters are generally low in settleable solids and often do not need primary clarification. The basis of design is the overflow rate, usually expressed in gallons/day/square foot (gpd/sq. ft.), which is equal to the flow in gallons/day divided by the surface area of the clarifier in square feet. It is obvious that overflow rate in itself does not totally determine the efficiency of a tank. In addition to the previously noted influent and effluent zone effects, the basin shape and size as well as the settling characteristics of each individual wastewater will influence the solids removal efficiency of a given sedimentation tank. Seasonal temperatures can also exert a significant influence on basin performance. The efficiency of primary sedimentation facilities varies widely.


Inlet zone
Outlet zone
Effective settling zone
Solids removal zone

FUNCTIONAL ZONES IN AN IDEALIZED SEDIMENTATION BASIN


Surface area A
V
Vs
h
ho
V
Vo
Direction of Flow Q
L
Lo

IDEALIZED SETTLING PATHS OF DISCRETE PARTICLE IN A HORIZONTAL FLOW TANK

FIGURE 8-7

SETTLING BASIN

Source: Environmental Protection Agency, Process Design Manual for Suspended Solids Removal

8.5.2.2 Secondary Sedimentation

The principles governing design of secondary sedimentation tanks are significantly different from those used for primary clarifiers. The major reason for the difference lies in the amount and nature of the solids to be removed. While primary settlers are designed on the basis of overflow rate alone, secondary clarifiers must be designed on the basis of overflow rate and solids loading. The greater concentration and lighter nature of the mixed-liquor suspended solids requires that the underflow concentration be considered in design. Settling rates are slower, as hindered settling prevails instead of free settling which occurs in primary basins. The information needed for an accurate determination can be obtained from laboratory settling tests. After the limiting solids loading has been determined on the basis of desired underflow concentration, the required area of basin can be computed using design flow and mixed-liquor suspended solids (MLSS) concentrations. The area required by this calculation and the area required by the overflow rate must then be compared, with the larger being the design size. A factor which strongly affects the limiting solids loading is the sludge volume index (SVI). As this value increases, sludge settling and concentration become more difficult.

TABLE 8-3
DESIGN PARAMETERS FOR CLARIFIERS

	Primary	Final
Overflow Rate (gpd/ft^2)	600-800	200-400*
Detention Time (Hours)	1-2	2-4
Depth (ft.)	7-12	8-12
Weir Rate (gpd/ft)	10,000 to 15,000	5,000 to 10,000

*For extended aeration process lower end of range is suggested.

The performance of secondary clarifiers is not generally cited, as they are considered integral to activated sludge systems; however, they can be rated on the basis of effluent quality to some extent. Usually, a large portion of the effluent organic content is associated with the suspended solids. Although no clarifier will completely remove all suspended solids, a properly designed facility should yield a good product if the biological process is working properly. Figure 8-8 illustrates a section through a typical circular clarifier.

Design considerations for secondary settling tanks should include the following:

- Inlets should be designed to dissipate the inlet velocity, to distribute the flow equally and to prevent short-circuiting. Channels should be designed to maintain a velocity of at least one foot per second at one-half design flow and to distribute the flow proportionately between parallel units. Corner pockets and dead ends should be eliminated.

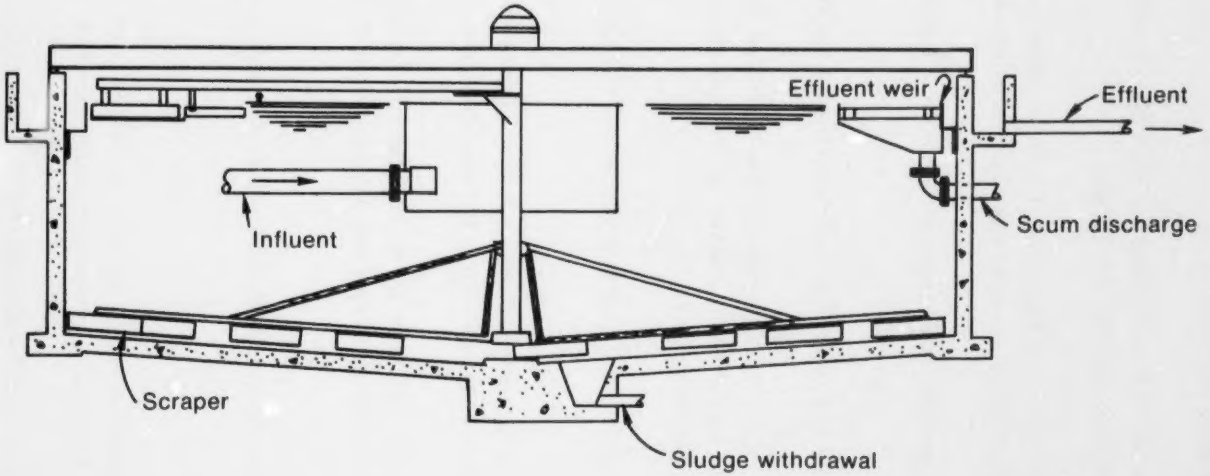

Effluent weir
Effluent
Influent
Scum discharge
Scraper
Sludge withdrawal

FIGURE 8-8

CLARIFIER SECTION

Source: Lockwood Greene Engineers, Inc.

- The minimum lengths of flow from inlet to outlet should be 10 feet unless special provisions are made to prevent short-circuiting.

- Scum baffles shall be provided ahead of outlet weirs.

- Overflow weirs shall be adjustable. Multiple weir troughs shall be placed sufficiently far apart to avoid excessive upward velocity between the troughs.

- All settling basins shall be designed to provide easy access for maintenance and protection to operators. Such features should include stairways, walkways and handrails.

- Provisions shall be made for convenient manual scum removal or for automatic equipment for scum removal.

- Removal of sludge from primary settling tanks shall be by direct pump suction.

- The liquid depth of mechanically cleaned settling tanks shall be as shallow as practical but not less than seven feet. Where activated sludge is returned to the settling tanks, the liquid depth of the tank shall not be less than eight feet.

- The minimum slope of the side walls of sludge hoppers shall be 1.7 vertical to 1.0 horizontal.

- Inlets, sludge collection, and sludge withdrawal facilities shall be so designed as to minimize density currents and to assure rapid return of sludge to the aeration tanks.

- Multiple units capable of independent operation are desirable and shall be provided in all plants where design flows exceed 40,000 gallons per day, unless other provisions are made to assure adequate treatment.

- Effective baffling and scum removal equipment shall be provided for all final settling tanks.

8.5.3 Filtration

Filtration of suspended or colloidal material is accomplished by passing the wastewater through a bed of granular material resulting in deposition of suspended solids in the bed.

Filtration is the most common form of advanced wastewater treatment practiced. It is used to treat effluent from secondary biological systems. Of the filter bed types, multi-media filters exhibit a superiority for filtration of activated sludge effluent because of the high volume of floc storage available in the upper bed and the polishing effect of the small media.

Multi-media beds are composed of various combinations of anthracite, sand, activated carbon, and resins. Conventional single-medium filters have a fine-to-coarse gradation in the direction of flow while multi-media is placed coarse to fine providing greater utilization of bed depth. The filtration units may be either gravity or pressure types as illustrated in Figures 8-9 and 8-10. Filter performance is directly related to the characteristics of the liquid to be filtered. Therefore, it is recommended that pilot plant studies be conducted to determine the optimum combination of filter materials. As a guide, the following tabulation of design parameters is presented:

TABLE 8-4
DESIGN PARAMETERS — MULTI-MEDIA FILTRATION

Hydraulic Load	6 to 12 gpm/ft^2
Solids Load	15 lb/day/ft^2
Depth	18 to 42 inches
Filter Run Time	8 hours

Design considerations for granular filters are summarized in EPA's Process Design Manual for Suspended Solids Removal and include the following:

- Variable hydraulic and suspended solids load must be considered to avoid short filter runs and excessive backwash. Equalization prior to filtration would be ideal.
- Coarse-to-fine filtration will allow reasonable filter runs.
- Auxiliary agitation of the media is essential to proper backwashing.
- The filtration rate and terminal head loss should be selected to achieve a minimum filter run length of 6 to 8 hours during peak conditions.
- High filtration rates and/or high influent suspended solids to the filters will cause high terminal head losses and may favor the use of pressure filters over gravity filters.
- At least two filters should be provided; each should be capable of handling peak design flows.

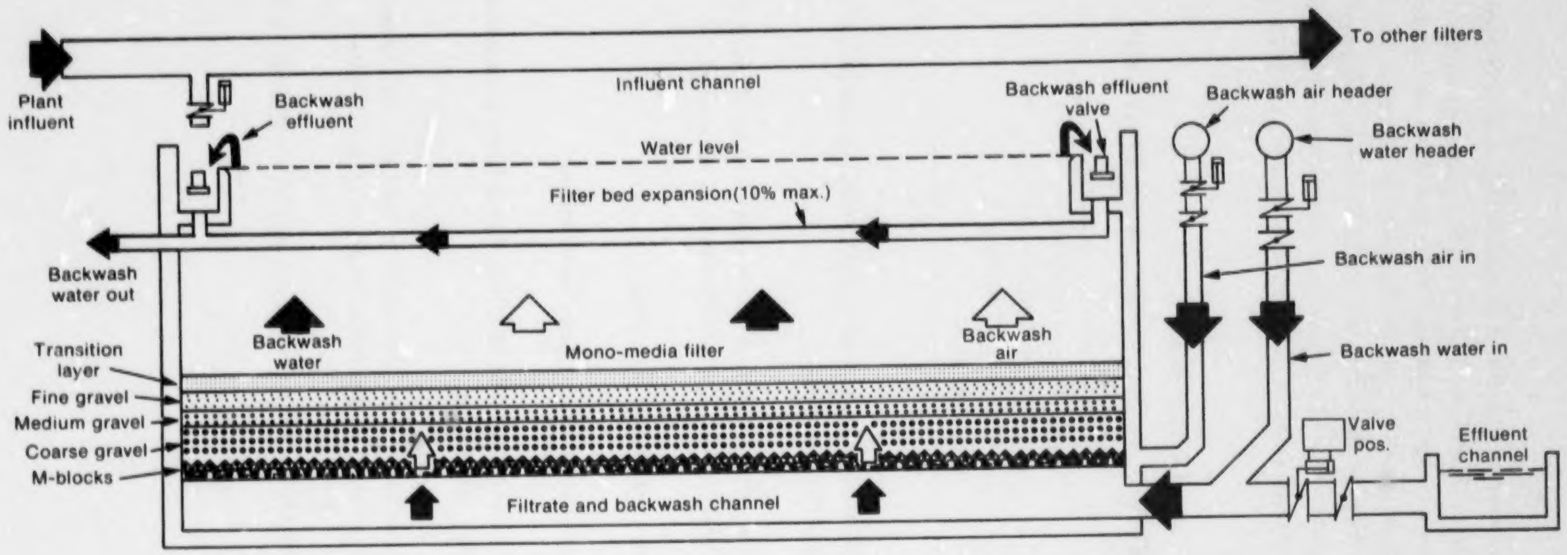

Plant influent
To other filters
Influent channel
Backwash effluent
Backwash effluent valve
Backwash air header
Backwash water header
Water level
Filter bed expansion(10% max.)
Backwash water out
Backwash air in
Backwash water in
Backwash water
Mono-media filter
Backwash air
Transition layer
Fine gravel
Medium gravel
Coarse gravel
M-blocks
Valve pos.
Effluent channel
Filtrate and backwash channel

FIGURE 8-9

GRAVITY-TYPE FILTER
(BACKWASH CYCLE)

Source: Environmental Engineer's Handbook

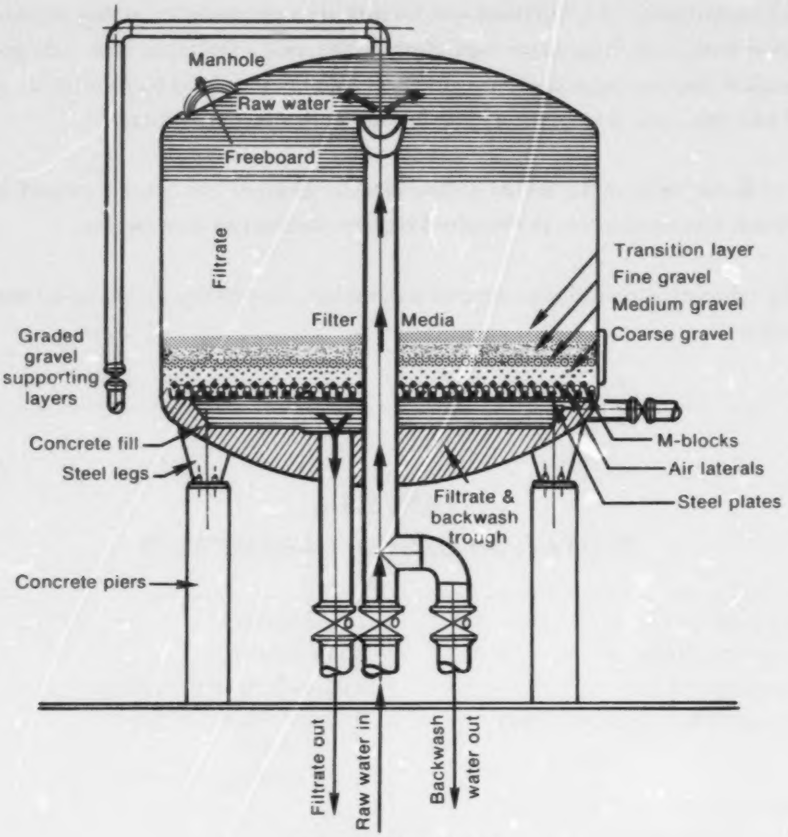

Manhole
Raw water
Freeboard
Filtrate
Filter
Media
Transition layer
Fine gravel
Medium gravel
Coarse gravel
Graded gravel supporting layers
Concrete fill
Steel legs
M-blocks
Air laterals
Steel plates
Filtrate & backwash trough
Concrete piers
Filtrate out
Raw water in
Backwash water out

FIGURE 8-10

PRESSURE-TYPE FILTER

Source: Environmental Engineer's Handbook

8.5.4 Flotation

The flotation process most commonly employed in textile waste treatment is that of dissolved air flotation. Fine air bubbles, less than 100 microns in diameter, are introduced into the effluent, where due to surface interactions they become attached to the solid particles. As the bubbles decrease the density of the solids, the separation takes place at the surface of the effluent rather than at the bottom of the settling basin. Wastewater flotation generally involves presurization of recycled effluent to avoid solids destruction. The raw waste is blended with this stream following pressure release. Wastewater constituents less dense than water (dye pigments, solvents, and grease and oil) float to the top of the unit and are removed by a surface skimmer. Particles heavier than water settle to the bottom of the unit and are removed by a sludge scraper mechanism and periodic blowoff.

The principal components of a flotation system include a pressurizing pump, air injection facilities, a retention tank, a back pressure regulating device, and a flotation tank unit (see Figure 8-11). If chemical addition appears warranted, as can be determined by laboratory jar tests, then a rapid mix tank and flocculation chamber are added to the system.

Advantages of flotation over the use of sedimentation include: less space required, thicker sludge produced, and an increase in dissolved oxygen content of wastewater.

The following tabulation provides a range of parameters used in the design of a dissolved air flotation system:

TABLE 8-5
FLOTATION DESIGN PARAMETERS

Hydraulic Loading	1 to 3 (gpm/ft^2)
Operating Pressure	30 to 75 (psig)
Gas-to-solids	0.01 to 0.06 (Weight Ratio)
Pressurization System Types	Recycle Flow (30 to 50%) Partial Flow Total Flow
Chemical Aids	Alum Lime Polyelectrolyte
Contaminant Removals (%)	
Grease & Oil	90+
BOD	30 to 50
S.S.	50 to 60

8.6 Equalization

Equalization is the process whereby the volume or analytical content of the waste may be discharged evenly to the treatment facility throughout the day. It may be necessary when batch discharges, intermittent rinsing, or intermittent operation produce wide variations in flow or analytical content. All treatment plants will operate more efficiently if the hydraulic, BOD, and other loads are more constant throughout the week.

The primary objective of flow equalization is to provide uniform conditions before entering physical, chemical, and biological treatment systems. Experience has shown that up to 24 hours detention or a volume equal to the mill's daily flow of equalization is recommended ahead of most biological systems. If there are wide flow variations, a flow equalizing method must be

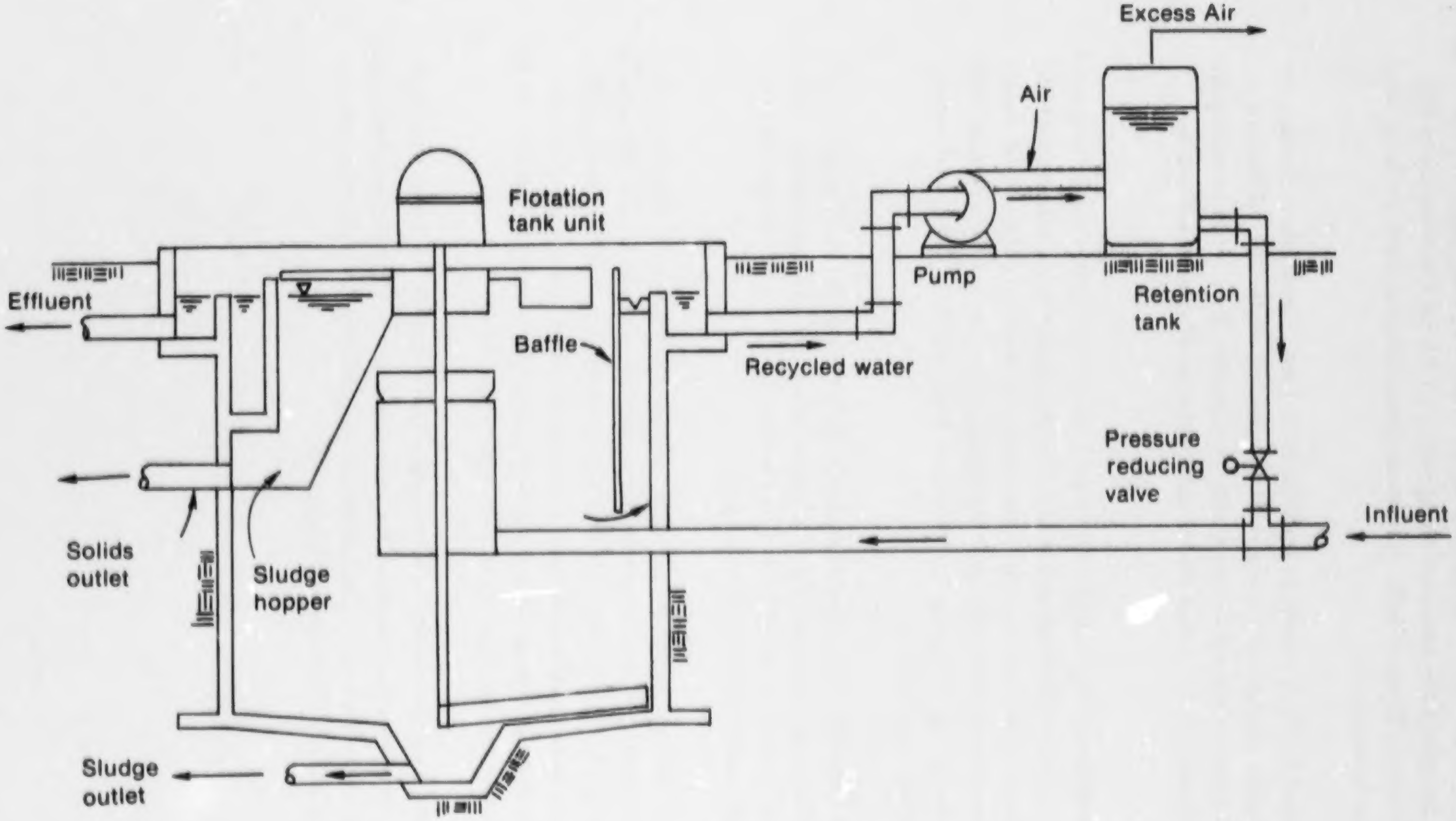

Excess Air
Air
Flotation tank unit
Pump
Retention tank
Effluent
Baffle
Recycled water
Pressure reducing valve
Influent
Solids outlet
Sludge hopper
Sludge outlet

FIGURE 8-11

DISSOLVED-AIR FLOTATION SYSTEM WITH RECYCLE FLOW PRESSURIZATION

Source: Lockwood Greene Engineers, Inc.

devised to prorate the discharge rate. This may be done by means of pumps, siphons, valves, or combinations of these. In some mills, tanks providing only 3 to 8 hour detention times will provide sufficient equalization. In many mills, continuous processing methods are being used and equalization will not be necessary.

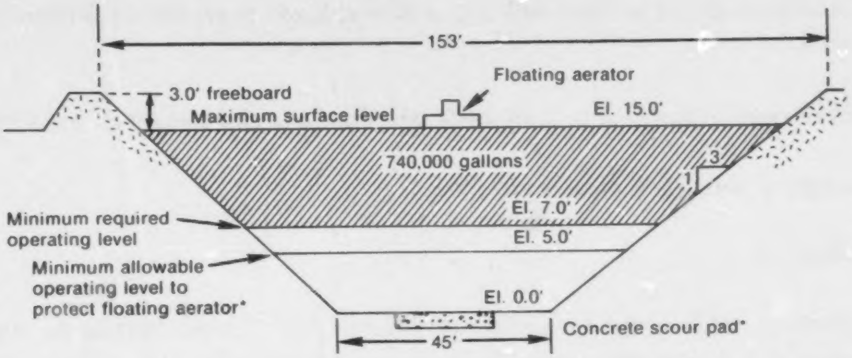
The major reason for equalization is usually to level the BOD loads. Variations in loading are eliminated by mixing highly concentrated waste with very diluted waste. The differences in production such as batch processing and the possibility of variation in the work week require equalization of waste streams to insure that the secondary treatment system will not be damaged.

If the major part of the BOD is being contributed by only one or two washes, only these need to be segregated at the source of discharge and stored in much smaller equalization tanks for controlled discharge. This is practicable for the desize and scour waste in cotton mills, scour and wash after fulling waste in woolen mills, and the knitting oil scour in polyester knit mills. Usually, segregating a volume equal to only 1 to 3% of the total mill flow will provide equalization for 50 to 90% of the total BOD.

Equalizing lagoons with detention times greater than one day are likely to develop odor problems through anaerobic decomposition and the resultant evolution of hydrogen sulfide. This has been known to occur even when the effluent pH is in the 11 to 12 range. Deep pockets, which collect sludge, will usually intensify the problem.

Some additional methods giving a degree of odor control include oxidation by hydrogen peroxide, oxygen, ozone and chlorine; odor neutralizing chemicals; lime addition to raise the alkalinity; and activated charcoal addition. Perhaps the best method is simply to add an aerator. Although the retention time in an equalization basin is usually too short to permit much oxidation, preaeration, in addition to keeping waste from becoming septic, has been found to aid in subsequent settling and may provide from 10 to 20% reduction in BOD.

Equalization also provides a significant degree of cooling which is usually sufficient to reduce hot textile wastewaters to temperatures suitable for a municipal sewer. Equalization basins may be constructed of earth, concrete or steel. Earthen basins are generally the least expensive. A cross section of a typical basin is illustrated in Figure 8-12.


153'
3.0' freeboard
Maximum surface level
Floating aerator
El. 15.0'
740,000 gallons
3
1
El. 7.0'
Minimum required operating level
El. 5.0'
Minimum allowable operating level to protect floating aerator*
El. 0.0'
45'
Concrete scour pad*

Volumes:
El. 0.0' to El. 7.0' approximately 260,000 gallons
El. 7.0' to El. 15.0' approximately 740,000 gallons
Total volume = 1,000,000 gallons

*These dimensions will vary with aerator design and horsepower

FIGURE 8-12

EARTHEN EQUALIZATION BASIN

Source: Environmental Protection Agency, Technology Transfer Seminar Publication — Flow Equalization

Following is a suggested tabulation of basic design parameters for an earthen equalization basin:

TABLE 8-6
DESIGN PARAMETERS FOR EQUALIZATION

Detention Time	24 Hours
Volume	Daily Mill Flow
Mixing Requirement	0.02 to 0.04 HP/1000 Gal.
Maintain Aerobic Conditions	1.15 to 2 ft^3 Air/Min./1000 Gal.
Side Slopes	3:1 to 2:1
Depth	Approximately 15 ft
Freeboard	3 ft
Minimum Operating Level	5 ft

General design considerations for equalization basins should include the following (15):

- Gravity discharge from equalization basin will require an automatically controlled flow-regulating device.
- A flow measuring device downstream of the basin will monitor equalized flow.

- Surface aerators should be fitted with legs or lift-out hooks to protect units when tank is dewatered.

- Facilities should be provided to flush solids and grease accumulations from basin walls.

- An emergency overflow should be provided.

8.7 Neutralization

Generally speaking, textile wastes are within a pH range of 5 to 12 units. Meeting the required effluent range of 6 to 9 units will require pH adjustment for some mills. Equalization will serve to reduce fluctuations in pH produced from batch dump processing and thus reduce or eliminate chemicals needed for neutralization.

Studies performed at Cone Mills during the period of 1950 to 1960 indicated that biological activated sludge processes develop specialized bacteria which will work efficiently within a range of 4 to 11 pH units. However, once these specialized bacteria and their optimum pH are developed, it is believed that changes of one or two pH units may cause upsets.

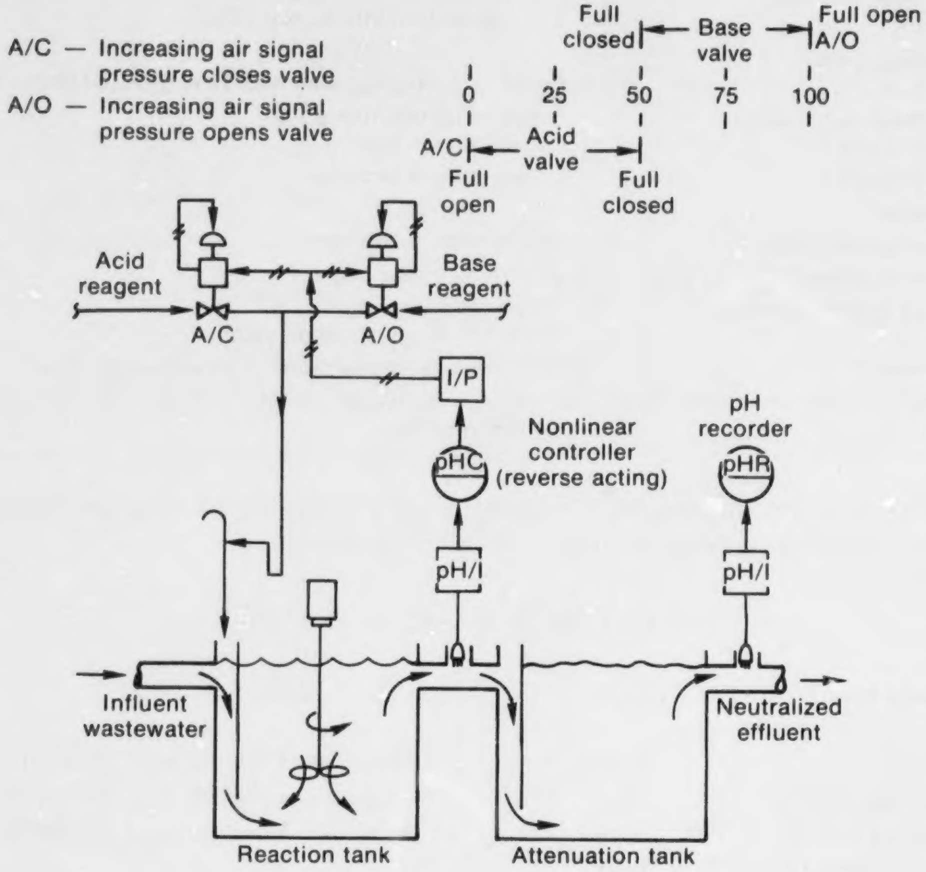
Additional studies by Masselli revealed that textile wastewaters with influent pH above 10 have been successfully treated in activated sludge systems since the biocarbonate alkalinity buffer in the aeration tank reduces pH to 10 or below on first contact. Bacterial oxidation subsequently produces acidic carbon dioxide from the organic carbon in the waste, and the remaining carbonate alkalinity will be reduced so that effluent pH's of 6.8 to 8.0 are developed.

Acidic effluents were rarely encountered in textile finishing until the advent of polyester knits. When large portions of knits are being dyed, the acetic acid used in dyeing may produce final effluents in the pH 5.0 to 6.0 range. Mills with acidic pH's may consider doing some cotton finishing since the use of sodium hydroxide in scouring and mercerizing will supply the necessary alkalinity.

Acid wastes may be neutralized using lime which is the least expensive alkali source available. Handling and feeding of lime, however, may be difficult as it must be slaked and fed as a slurry. Lime also reacts slowly and has the tendency to settle out in piping and equipment. Easiest to handle and control is 50% sodium hydroxide (caustic soda).

Alkaline wastes may also be neutralized using strong acids having reaction rates which are practically instantaneous or by the addition of boiler flue gases which contain sufficient carbon dioxide and sulphur dioxide to reduce the pH of most caustic liquors.

Batch neutralization may be suitable for waste flows under 100,000 gpd. When wastewaters exhibit a highly variable pH, it is usually more effective to stage neutralize (see Figure 8-13). Reagents are added in a step-wise fashion to dampen fluctuations.



A/C — Increasing air signal pressure closes valve
A/O — Increasing air signal pressure opens valve
Full closed
Base valve
Full open
A/O
0
25
50
75
100
A/C
Acid valve
Full open
Full closed
Acid reagent
Base reagent
A/C
A/O
I/P
Nonlinear controller (reverse acting)
pHC
pH recorder
pHR
pH/I
pH/I
Influent wastewater
Neutralized effluent
Reaction tank
Attenuation tank

FIGURE 8-13

CONTROL OF VARIABLE pH

Source: Environmental Engineer's Handbook

Regulation of pH by chemical means is usually accomplished by a system consisting of a chemical storage tank, metering pump or control valve, reaction tank or compartment with agitator, and control instruments (see Figure 8-14). Control methods used include: feed forward, proportional and feedback systems. Following is a tabulation of design considerations for each of the above.

TABLE 8-7
NEUTRALIZATION SYSTEM DESIGN PARAMETERS

Chemical Storage Tank	Liquid - use stored supply vessel Dry - dilute in a mix or day tank
Reaction Tank:	
Size	Cubic or cylindrical with liquid depth equal to diameter
Retention Time	5 min. to 30 min. (lime - 30)
Influent	Locate at tank top
Effluent	Locate at tank bottom
Agitator:	
Propeller Type	Under 1000 gallon tanks
Axial Flow Type	Over 1000 gallon tanks
Peripheral Speeds	12 fps for large tanks 25 fps for tanks less than 1000 gal
pH Sensor	Submersible are preferred to flow through type
Metering Pump or Control Valve	Pump delivery range limited to 10 to 1; valves have greater ranges.

The selection of neutralizing agents will depend upon availability, chemical cost and feeding methods. Following is a tabulation of generally acceptable reagents:

COMMON NEUTRALIZATION REAGENTS

Alkalinity Source	*Form*	*Remarks*
Dry Lime	Powder	280 lbs/MG Yields 60 mg/1 Alkalinity
Caustic Soda (50%)	Liquid	63 gal/MG Yields 60 mg/1 Alkalinity
Ammonia (57.6%)	Liquid	81 gal/MG Yields 60 mg/1 Alkalinity
Sodium Carbonate	Solid	
Trisodium Phosphate	–	
Limestone	Chips	
Waste Alkali	–	
Acid Source		
Sulfuric Acid (66 Be°)	Liquid	
Nitric Acid (100%)	Liquid	
Hydrochloric Acid (22 Be°)	Liquid	
Carbon Dioxide	Gas	
Sulfur Dioxide	Liquid	
Flue Gas	Gas	
Waste Acid	Liquid	

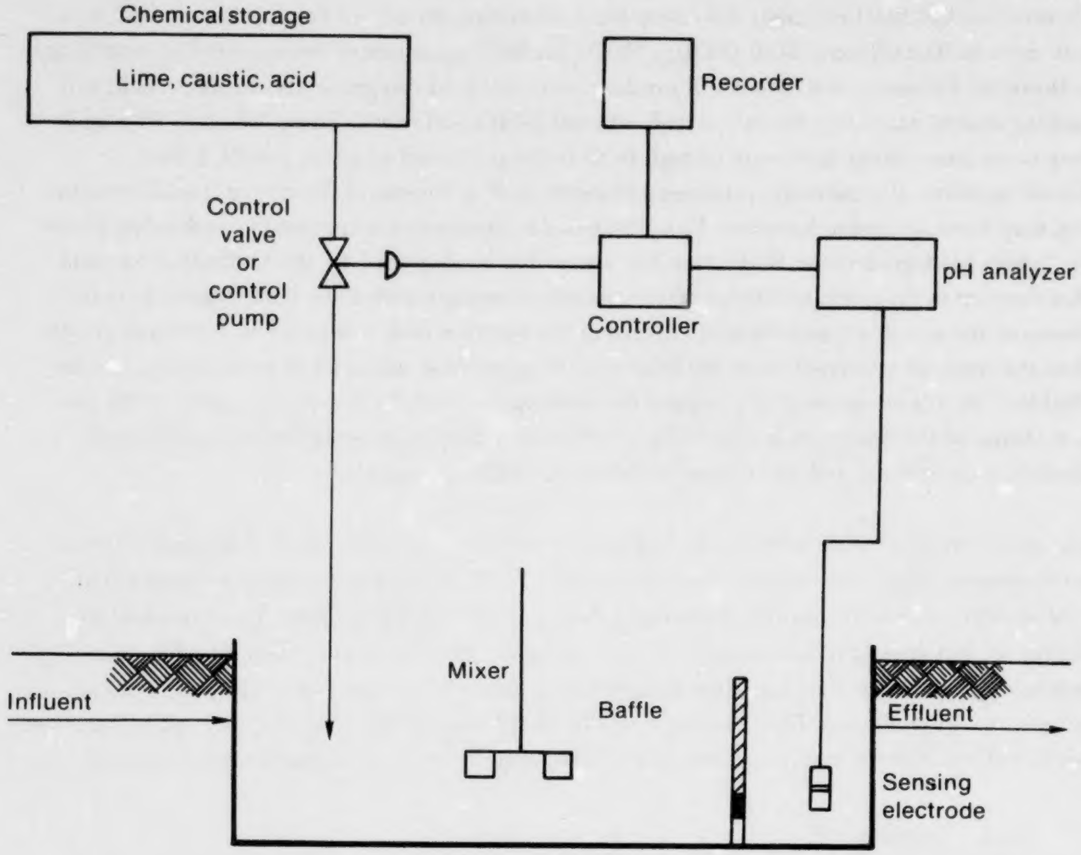

Chemical storage
Lime, caustic, acid
Recorder
Control valve or control pump
Controller
pH analyzer
Mixer
Influent
Baffle
Effluent
Sensing electrode

FIGURE 8-14

pH CONTROL SYSTEM

Source: Lockwood Greene Engineers, Inc.

8.8 BOD/COD Reduction

It should be noted that COD, total oxygen demand and TOC are rapid analytical measures of organic matter and are used in conjunction with the slower BOD determination. Consequently, the same procedures indicated for BOD removal are used for COD removal.

In some instances, there may be adequate BOD removal but inadequate COD removal, indicating that soluble or colloidal nonbiodegradable organic matter is present in the waste. If further COD removal is required, all efforts to identify the nature of the compounds contributing the COD should be made, and biodegradable process chemicals should be substituted for the nonbiodegradable compounds. If this is not possible, treatment by chemical coagulation or activated carbon will have to be used, and costs may be doubled or tripled.

Measurement of BOD is usually necessary for determining the size of treatment units and aeration devices. The ultimate BOD (BOD_U, BOD_L, or BOD_{20}) is sometimes required by regulatory authorities. Excessive BOD loads will produce zero dissolved oxygen in the aeration tank, and bulking sludge, anaerobic odors and high effluent BOD's will result. These "shock" BOD loads may come from dump discharges of high BOD baths at the end of a run, a shift, a week or before vacation. Occasionally, processing changes, such as the use of Xylene or Varsol in scouring, may cause excessive increases. Many chemical compounds are apparently nonbiodegradable or slightly biodegradable in BOD tests, but are readily biodegraded by the acclimated bacteria that develop in the activated sludge after continuous contact with these compounds. In many instances the actual oxygen demand exerted in the aeration tank will be 10 to 100 times greater than the demand estimated from the BOD test. If appreciable amounts of such chemicals with "hidden" BOD's are present, the oxygen demand may exceed the aeration capacity of the system. Some of the compounds with hidden BOD's are cellulose, polyacrylic acids, polyvinyl alcohol, naphthalene, and alkyl benzene sulfonate (ABS) detergents.

The temperature of wastewaters is an important consideration in selection of biological treatment systems. High temperature wastes in excess of 100° F are not amenable to short detention systems such as conventional activated sludge or even trickling filters. Low temperature wastes are not amenable to treatment in aerated lagoon systems in cold climates where temperatures drop below freezing. High temperatures above 95° F are reported to produce dispersed growths and lower BOD efficiencies. The likelihood of such temperatures will be increased when water use is reduced, therefore, heat reclamation by heat exchangers may be required.

8.8.1 Lagoons

Lagoons can be divided into five general classes. They are high-rate aerobic ponds, facultative ponds, anaerobic ponds, tertiary ponds (maturation or polishing ponds) and aerated lagoons. High-rate ponds and facultative ponds are also called oxidation ponds.

In high-rate aerobic ponds, algae production is maximized by allowing maximum light penetration in a shallow pond. These ponds are generally only 12 to 18 inches in depth and are intermittently mixed. The main biological processes are aerobic bacterial oxidation and algae photosynthesis. Organic loadings range from 60 to 200 pounds BOD_5 per acre per day. Usually 80 to 95% of the waste organic matter is converted to algae.

These ponds cover a large area and have waste detention times as great as several months. BOD loading must be light to avoid anaerobic conditions and the generation of odors. While some means of controlling the water level is usually necessary (variable weirs, etc.), the equipment cost for such is minimum. The major portion of this system's cost is for acquiring land.

Facultative ponds are perhaps the most numerous of the pond systems, having a depth of 3 to 8 feet. The greater depth allows two zones to develop: an aerobic surface zone and an anaerobic bottom layer. Oxygen for aerobic stabilization in the surface layer is provided by photosynthesis and surface reaeration, while sludge in the bottom layer is anaerobically digested. Loadings generally range from 15 to 80 pounds BOD per acre per day, and BOD_5 removal from 70 to 95%, depending on the concentration of algae in the effluent.

Tertiary ponds are generally used for polishing effluents from conventional secondary processes, such as trickling filter or activated sludge. Settleable solids, BOD_5 fecal organisms, and ammonia are reduced. Algae and surface aeration provide the oxygen for stabilization. BOD_5 loadings are generally less than 15 pounds BOD_5 per acre per day.

Aerated lagoons have been used successfully for many years in textile waste treatment. They require only 3 to 5% of the land needed for high-rate ponds. They are 8 to 15 feet deep and have waste detention times of 2 to 10 days, although 5 days is usually appropriate if the heat loss is great. Oxygen is introduced into the lagoon either by fixed mechanical turbine-type or floating propeller-type low speed aerators, or a diffused air system (see Figure 8-15). If the turbulence level is insufficient to maintain solids in suspension, then insert solids and nonoxidized biological solids settle to the bottom of the basin where they undergo anaerobic decomposition. This is sometimes referred to as a facultative lagoon. If the turbulence level in the basin is increased to maintain solids in suspension, the system becomes analogous to the activated sludge process without solids recycle. In order to obtain a good quality effluent from the aerated lagoon system, the biological solids should be separated, generally by a settling basin.

BOD and suspended solids reductions vary widely from 50 to 90+% depending upon detention time and temperature as well as the degree of mixing. Aerated lagoon design is based upon the following factors: BOD removal rate, oxygen requirements, temperature effects, and energy required for mixing. BOD removal rate with or without nutrient addition can be determined in the laboratory by batch aeration of waste seeded with an acclimatized effluent. Oxygen requirements are computed knowing the BOD of the waste and the amount of organisms wasted from the system per day. Temperature affects treatment by reducing biological activity and treatment efficiency. Design calculations include temperature effects. The BOD removal rate is lower in winter than in summer and, therefore, optimum design for detention time is controlled by winter temperatures; however, oxygen requirements will usually be controlled by summer conditions in the basin. Mixing requirements vary with the type of aerator and lagoon geometry. It is important to check mixing because in many cases the energy required for mixing is greater than that for oxygen transfer.

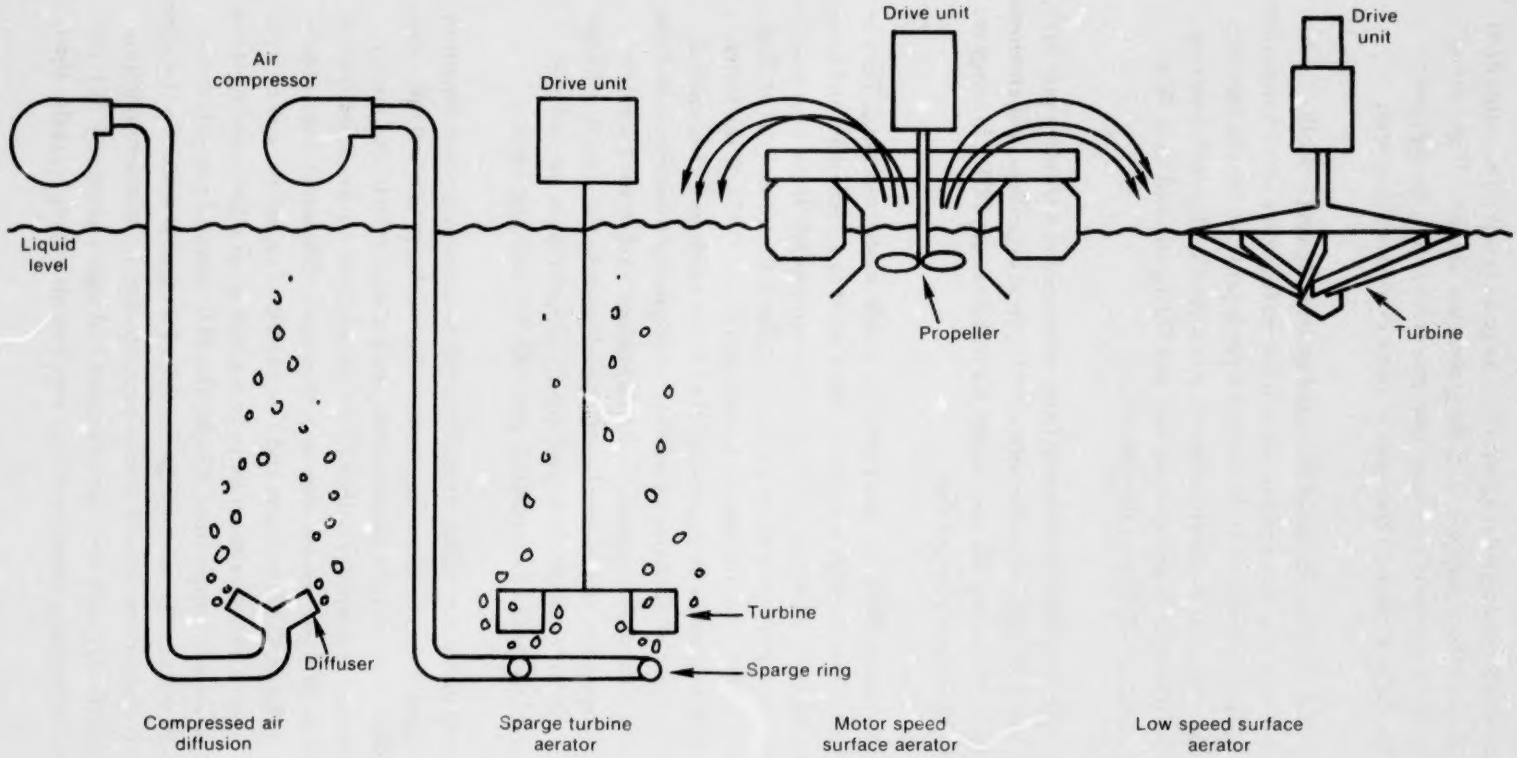

Air compressor
Drive unit
Drive unit
Drive unit
Liquid level
Propeller
Turbine
Turbine
Diffuser
Sparge ring
Compressed air diffusion
Sparge turbine aerator
Motor speed surface aerator
Low speed surface aerator

FIGURE 8-15

OXYGENATION AND MIXING DEVICES

Source: Environmental Engineer's Handbook

Following is a tabulation of suggested design parameters for aerated lagoons:

TABLE 8-8
SUGGESTED DESIGN PARAMETERS FOR AERATED LAGOONS

Detention Time	2 to 10 days
Depth	6 to 15 feet
Side Slopes	3:1 to 2:1
Oxygen Utilization	36 lb. BOD/day/HP
BOD Removal	50 to 90+%

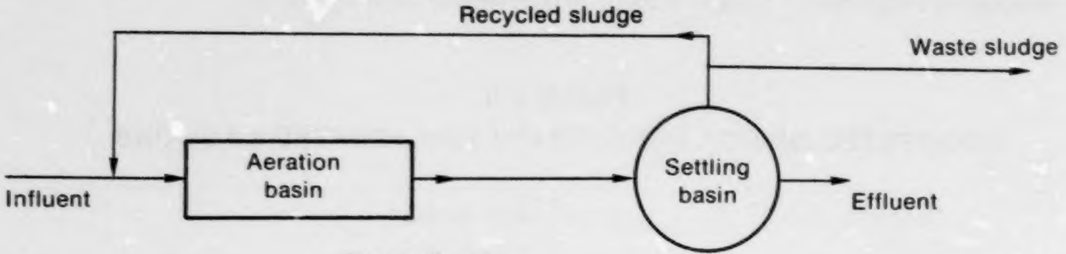
It is generally desirable to divide the required lagoon volume into at least two basins for operational flexibility. Another possibility is to arrange lagoons in a series of up to four units.

For details of lagoon inlets, outlets and dike construction see section 8.8.7 entitled "Polishing Ponds".

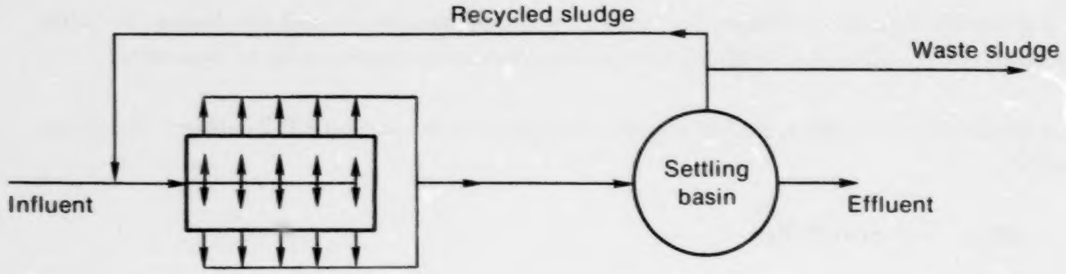
8.8.2 Activated Sludge

The activated sludge process was developed by Ardern and Lockett in England during 1912 – 1914, and was named for the activated sludge produced. The activated sludge process basically involves two unit operations; contacting and liquid-solids separation. The contacting portion involves the mixing of wastewater and microorganisms. The second unit operation involves the liquid-solids separation step. Since the presence of microorganisms is the key to biological oxidation, it is necessary to return them to the contactor. Therefore, a liquid-solids separation unit removes the microorganisms from the treated wastewater. This separation not only allows for the collection and recycling of the valuable microorganisms, but also results in clarification of the wastewater. The recycling of microorganisms is the unique aspect of the activated sludge process. If sludge is not returned quickly enough, denitrification and rising sludge can occur. Denitrification can result in the formation of a layer of biological solids over the clarifier surface. It is necessary in this case to agitate the scum layer to release nitrogen gas and to permit it to resettle. Generally, spraying the surface with water will break up the scum without excessive loss of solids. By definition, activated sludge involves the concept of the return of microorganisms to the contactor to achieve maximum treatment efficiency in the shortest time possible.

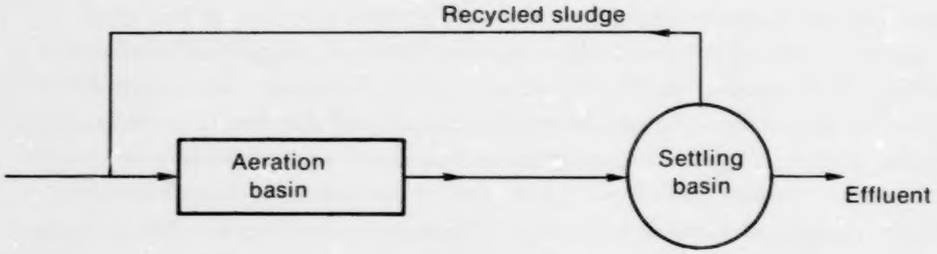
Many modifications of the conventional (original) activated sludge process have become standardized since its inception. They are complete-mix, step-aeration, tapered-aeration, modified aeration, contact-stabilization, extended-aeration, high-rate aeration, oxidation ditch, Kraus-process and pure-oxygen systems. Figure 8-16 illustrates schematically the conventional, complete mix and extended aeration methods. For textile wastewaters, extended-aeration activated sludge process is usually preferred. This section will discuss the design basis of conventional and extended-aeration activated systems.


Recycled sludge
Waste sludge
Influent
Aeration basin
Settling basin
Effluent

Conventional


Recycled sludge
Waste sludge
Influent
Settling basin
Effluent

Complete - Mix


Recycled sludge
Aeration basin
Settling basin
Effluent

Extended aeration

FIGURE 8-16

ACTIVATED SLUDGE PROCESSES

Source: Lockwood Greene Engineers, Inc.

The conventional process is normally designed for an F/M ratio (F/M ratio is defined as the amount of biodegradable organic material available to a given amount of microorganisms per unit of time = Food/Microorganisms) of 0.2 to 0.5 lb. BOD_5 per lb. MLSS/day. For municipal wastewaters containing approximately 250 mg/1 BOD_5, the MLSS concentration is maintained at approximately 2,000 mg/1, and the contactor retention time ranges between 3 and 5 hours. The degree of treatment normally achieved with the conventional activated sludge treatment is 90% suspended solids removal. For textile wastewater, an F/M ratio of 0.25 lb. BOD_5 per lb. MLSS/day is normally preferred. The MLSS concentration is maintained at 2,500 mg/1, and the retention time ranges between 12 and 24 hours.

Having a small volume to dissipate a surge, shock loads do have an adverse effect on a conventional activated sludge system. Therefore, the application of the conventional activated sludge process to textile wastewater results in the need for pretreatment facilities such as equalization basins and neutralization equipment. Color removal by conventional activated sludge is usually less than 50%. High sludge production in the conventional activated sludge system may be a costly factor.

8.8.2.1 Extended Aeration

The extended aeration modification of the activated sludge process is similar to the conventional activated sludge process, except that the mixture of activated sludge and raw materials is maintained in the aeration chamber for longer periods of time. With domestic wastewater, the F/M ratio is usually satisfied with 24-hour detention period. For textile wastewaters, aeration periods of 36, 48, 60, 72, 96 or over 120 hours may be required. During this prolonged contact between the sludge and raw waste, there is ample time for organic matter to be absorbed by the sludge and also for the organisms to metabolize the organic matter which has been built up into the protoplasm of the organism. Hence, in addition to high organic removals from the wastewaters, up to 75% of the organic matter of the microorganisms is decomposed into stable products and consequently less sludge will have to be handled.

A highly purified effluent is possible with BOD_5 removals greater than 90%. Also, due to the longer detention time and consequently larger volumes, the process is more resistant to upsets from shock loads.

In extended aeration, as in the conventional activated sludge process, it is necessary to have a final sedimentation tank. Some of the solids resulting from extended aeration are finely divided and therefore settle slowly, requiring a longer period of settling. Clarifiers should be equipped with mechanical sludge removal equipment and in some cases an oil removal device. See section 8.5.2 for the design of final clarifiers.

Oxygen is introduced into the aeration tank by means of mechanical aerators or diffused air systems. Most newer treatment plants use mechanical aerators, either fixed or floating. If effluent BOD is above 500 mg/1 and soluble, both diffused and mechanical aeration may be used

TABLE 8-9
EXTENDED AERATION DESIGN PARAMETERS

Retention Time	3 to 5 days
Depth	10 ft. minimum; 15 ft. maximum
Recirculation of Activated Sludge	100 percent
Excess Sludge Produced	0.1 to 0.2 lb/lb BOD removed
Organic Loading (F/M)	0.04 to 0.1 lb BOD/day/lb MLVSS
Sludge Volume Index	150 ml per gram of settled MLSS
Mixed Liquor Volatile Suspended Solid (MLVSS) Concentration in Reactor	2500 to 3500 mg/l
Aerator Type:	
Low-speed Surface Aerator	1.75 HP/1000 cu. ft. volume of tank
(Power Level)	(1 HP/36 lb BOD loading/day) or (70 HP/1 MGD Flow)
Diffused Air System	$\frac{\text{1,500 cu. ft. of tank}}{\text{lb/BOD Loading/Day}}$
(Air Requirement)	$\left(\frac{\text{56 cu. ft. air}}{\text{cu. ft. volume of tank}}\right)$ or
	$\left(\frac{\text{3.5 x 10 cu. ft. air}}{\text{1 MGD Flow}}\right)$
D.O. in Mixed Liquor	2 mg/l
Overflow Rate for Clarifiers	300 gpd/ft^2

together. This method releases compressed air below the mechanical aerator. The oxygenation capacity of an aeration device is a function of the standard efficiency of the aerator, temperature, the oxygen deficit, and dissolved impurities which may affect molecular oxygen transfer. Standard transfer efficiencies for surface aerators may vary from 2.5 to 3.5 lb. oxygen/HP.-hr. Oxygen deficit is the difference between saturated dissolved oxygen concentration and the operating dissolved oxygen level in the basin. When calculating aeration requirements, it is recommended that oxygen requirements be based on the 90 percentile (statistical distribution) BOD loading. See Table 8-9 for suggested design parameters for extended aeration.

Flotation is sometimes used instead of a clarifier to handle the waste activated sludge when bulking problems occur with settling type clarifications. Conventional recycle pressurization is used with a solids loading rate of approximately 1.5 lbs./hr./sq. ft.

The advantages of flotation include:

- Sludge concentration of 3 to 4% can be expected as compared to less than 1% for conventional clarifiers.
- Clarified effluent contains about 5 mg/1 of BOD, and this may eliminate the need for possible reaeration.

8.8.3 Nutrient Addition

Supplemental nutrients, if required to maintain a BOD: N:P ratio of 100:5:1 for high-rate synthesis, 100:3:0.5 for medium-rate synthesis and 100:2:0.3 for low-rate synthesis should be added to the waste stream as it enters the aeration basin. Indications are that a minimum nitrogen content of 7% and minimum phosphorus content of 1.2% of the volatile suspended solids are necessary to avoid a reduced BOD removal efficiency. In textile wastes, sufficient phosphate is usually present (concentration of inorganic phosphorus is approximately 9 mg/1), but occasionally a nitrogen source may have to be added. Quantities of N & P are calculated by subtracting the lbs./day of each in the waste from the lbs./day required to obtain the above ratio. Feeding excess nitrogen is not desirable as ammonia has a high potential oxygen demand (423%) as well as a high chlorine demand.

Following is a suggested list of nutrients sources:

Nutrient	*Form*	*Remarks*
Nitrogen	Anhydrous Ammonia	Provides Alkalinity, 82.3% N
	Domestic Sewage	Provides Acidity
	Ammonium Nitrate	35% N
	Ammonium Sulfate	21.2% N
Phosphorus	Trisodium Phosphate	Provides Alkalinity
	Domestic Sewage	Provides Acidity
	Ammonium Phosphate	Provides Nitrogen
	Di-Ammonium Phosphate	Provides Nitrogen

Nutrients, preferably in a gas or liquid form, are added to the waste stream under pressure by metering pumps or by gravity (see Figure 8-17).

8.8.4 Fixed Film Biological Reactors

8.8.4.1 Trickling Filters

Trickling filters usually contain media composed of rock, redwood or synthetic material. The hydraulic loading of rock filters is usually 10 to 40 million gallons per acre per day; the BOD loadings are from 0.015 to 3.0 lbs. BOD per cubic yard of material per day. Rock filters are usually 10 to 50 feet deep, and may require large land areas for settling and recirculation, which is usually on a ratio of 1:1 to 10:1 raw waste to treated effluent.

The relatively new synthetic filter media have several advantages over the rock filter types. They are lighter than rock and can be stacked 30 feet high (see Figure 8-18). The surface area per unit volume is controlled when the media is manufactured so that more space for bacterial attachment is provided. The hydraulic loadings can be as high as 20 to 40 million gallons/acre/

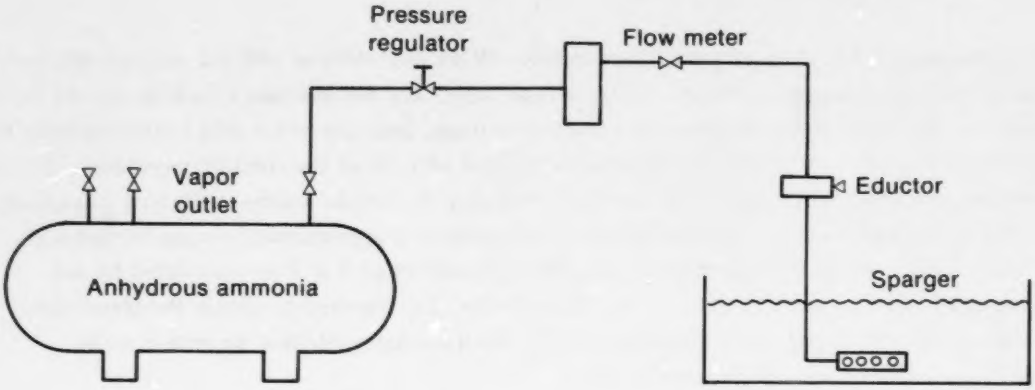

Pressure regulator
Flow meter
Vapor outlet
Eductor
Anhydrous ammonia
Sparger

FIGURE 8-17

NITROGEN FEED SYSTEM

Source: Lockwood Greene Engineers, Inc.

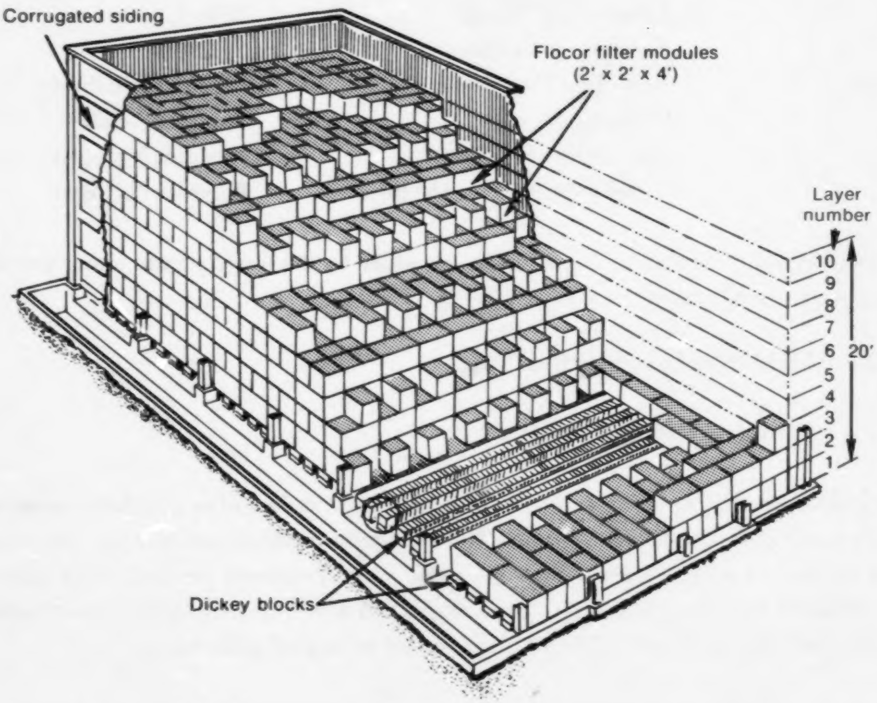

Corrugated siding
Flocor filter modules
(2' x 2' x 4')
Layer number
10
9
8
7
6
5
4
3
2
1
20'
Dickey blocks

FIGURE 8-18

BIO-OXIDATION TOWER

Source: Ethyl Corporation

day and BOD loading of 5 to 10 lbs. per cubic yard per day can be obtained. Above ground units may be adversely affected by cold weather.

The rate of waste addition to the filter media may be classified as standard or high rate loading. The difference is that standard rate addition is intermittent for loading periods of 5 minutes or less, whereas high rate types are continuously fed by means of a variable recirculation system. The standard rate filter has a hydraulic loading of 4 million gallons per day per acre, organic loadings of 15 lbs. of BOD per acre-foot per day, and intermittent releasing of dead bacteria. The sludge from the process is a black, highly oxidized product containing light, fine particles and a highly nitrified effluent with less than 20 milligrams of BOD per liter. The effluent is usually discharged after one pass through the filter. The corresponding hydraulic load, organic load, and sludge discharge rate of the high rate type are respectively: 10 to 30 million gals./day/acre, 30 lbs. of BOD/acre-foot/day, and continuous. The sludge produced in the secondary settling tank is brown in color and not fully oxidized; the effluent is not fully nitrified and has a BOD of 30 or more milligrams per liter. Recirculating the effluent makes the final discharge as good as it is with the standard rate; however, the efficiency is lowered appreciably.

The term single stage trickling filter refers to the process of passing the waste through one trickling filter and then to a secondary settling tank. Two stage treatment refers to the passing of the effluent from primary settling through two trickling filters in series before the secondary settling stage. With single stage treatment, BOD removal is about 50 to 75%. Although the two-stage method has a higher rate of BOD reduction than the single stage method, it is more costly than the activated sludge method. Trickling filters may also be used as roughing filters ahead of an activated sludge basin. This works best at soluble BOD levels above 200 mg/1.

Trickling filters exhibit variable behavior, and this is their greatest shortcoming. They are sensitive to changing characteristics expected in textile wastes, and they allow little modification of operation to optimize treatment.

8.8.4.2 Rotating Disks

The rotating-biological-disk system consists of large-diameter, lightweight plastic disks, which are closely packed and mounted on a horizontal shaft located in a semicircular tank. A series of these units treats the waste, which flows from one tank to another. The microorganisms present in the wastewater adhere to the plastic surfaces as they rotate through the tank. The wastewater is picked up on the surface of the disk and the portion that is not submerged absorbs oxygen from the atmosphere. The microorganisms then aerobically degrade organic matter present in the waste. As they multiply, excess microorganisms are sloughed off the disks into the wastewater. Mixing action provided by the disks keeps solids suspended. After treatment through a series of rotating biological disks, a final clarifier removes suspended solids. A BOD_5 reduction of over 90% may be achievable with a multi-stage rotating biological contactor.

Biological rotating disks have been found to be flexible with respect to varying organic and hydraulic loads, but the short detention times of each unit make them vulnerable to toxic shock loads. Reduction in waste temperature would be slight, and high influent temperature would adversely affect treatment. This treatment method offers the advantage of low space requirements and, in some instances, may be economically competitive with other methods. Four-stage treatment by biological rotating disks has demonstrated BOD removals from 60 to 95% for domestic wastewaters (see Figure 8-19). The final effluent is well oxygenated. Oxidation of ammonia, sulfides and phenols would likely take place. Pilot installations are presently treating textile wastes in North Carolina. In one instance, biological disks are used to reduce further the BOD of activated-sludge effluent from an existing plant. The disks are also useful as a nitrogen removal stage.

Table 8-10 and 8-11 present suggested design parameters for trickling filters.

TABLE 8-10
TRICKLING FILTER DESIGN PARAMETERS

Rock Media	
Hydraulic Loading	3.5 mgd/acre
BOD Loading	36 lb. BOD/1000 cu. ft./day
Recirculation Rate	5:1 to 10:1
Media Size	2" to 4" Granite
Filter Bed Depth	14 feet
Synthetic Media	
BOD Loading	51 to 93 lb. BOD/1000 cu. ft./day
Recirculation Rate	2:1
BOD Removal	75 to 78%
Filter Bed Depth	21+ feet

TABLE 8-11
ROUGHING FILTER DESIGN PARAMETERS

Rock Media	
Hydraulic Loading	6.9 mgd/acre
BOD Loading	60 lb/1000 cu. ft./day
Recirculation Rate	1.7:1
Filter Bed Depth	6 feet

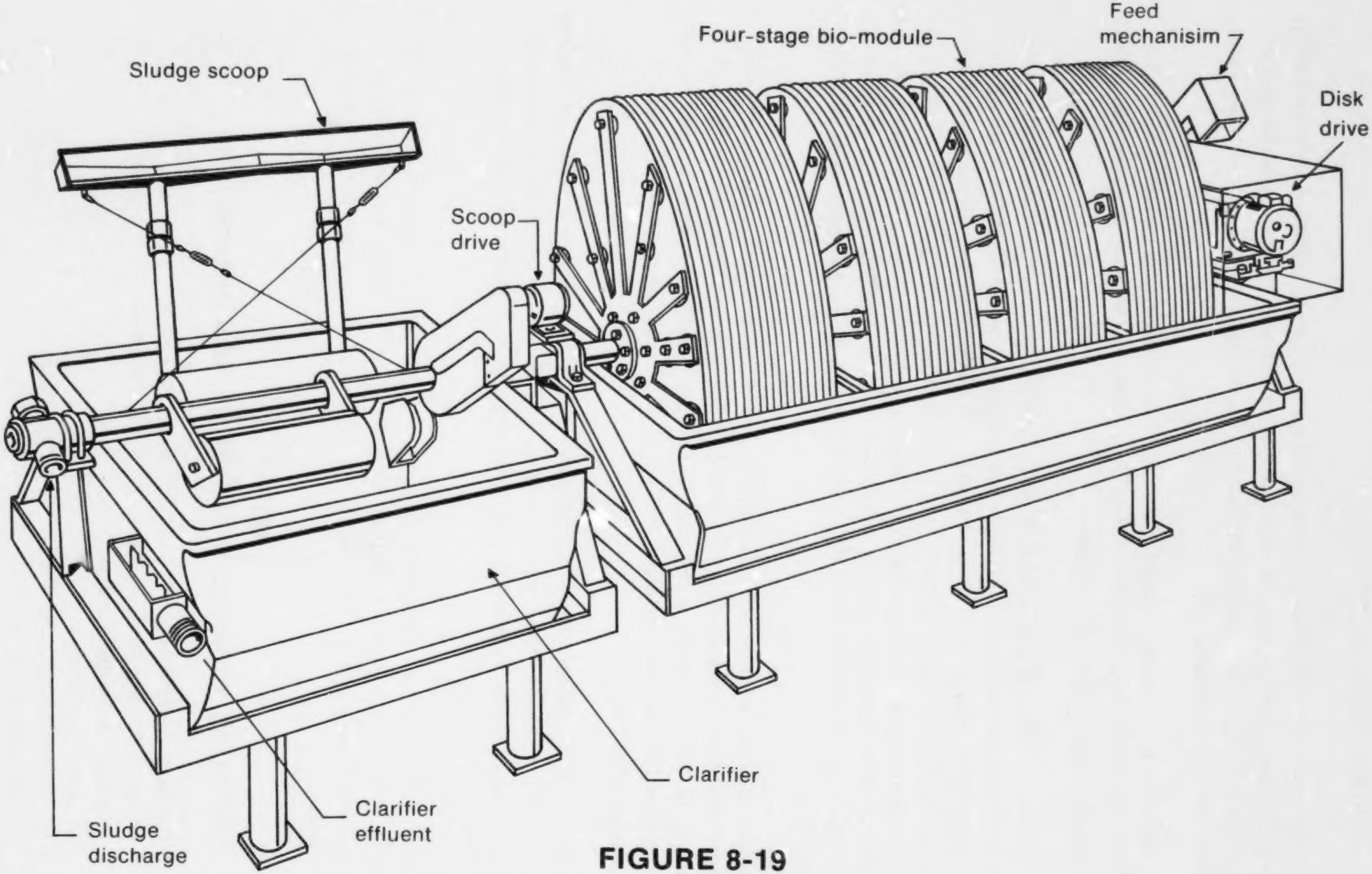

Sludge scoop
Four-stage bio-module
Feed mechanisim
Disk drive
Scoop drive
Clarifier
Clarifier effluent
Sludge discharge

FIGURE 8-19

BIOLOGICAL ROTATING DISK

Source: Autorol Corporation

8.8.5 Activated Carbon Catalyst

BOD/COD and color have been shown to be reduced markedly when activated carbon (granular or powdered) has been placed in the aerobic reactor of an activated sludge system. In addition activated carbon will reduce the foaming tendency of the aeration system, and the sludge will act as a sink to trap heavy metals.

Though most testing has been with granular activated carbon, powdered carbon is now being considered because it can be produced considerably cheaper, and because of the smaller particle size, the adsorption rate is much more rapid.

Recent testing at a textile finishing plant (16) indicated that the carbon feeding position does not appear to be critical. Carbon can be simply fed using an open top 55-gallon drum with a water spray pipe in the center. The carbon is washed out of the tank through a drain in the bottom to feed points along the aeration basin (see Figure 8-20). Granular activated carbon was pilot tested at approximately 5 grams per liter (one time addition). It was found during the test period of nine months that sludge wasting was required on a regular schedule to produce constant good color removals and to reduce the heavy metal concentration adsorbed in the sludge (see Figure 8-21).

When starting a system, carbon is fed daily until the mixed liquor suspended solids activated carbon level is maintained at approximately 25% of the MLSS with a relatively low level of sludge wasting. The level of carbon in the MLSS is important since the continuous build-up of inert material (possibly metals) can reduce the biologically viable component of the mixed liquor suspended solids.

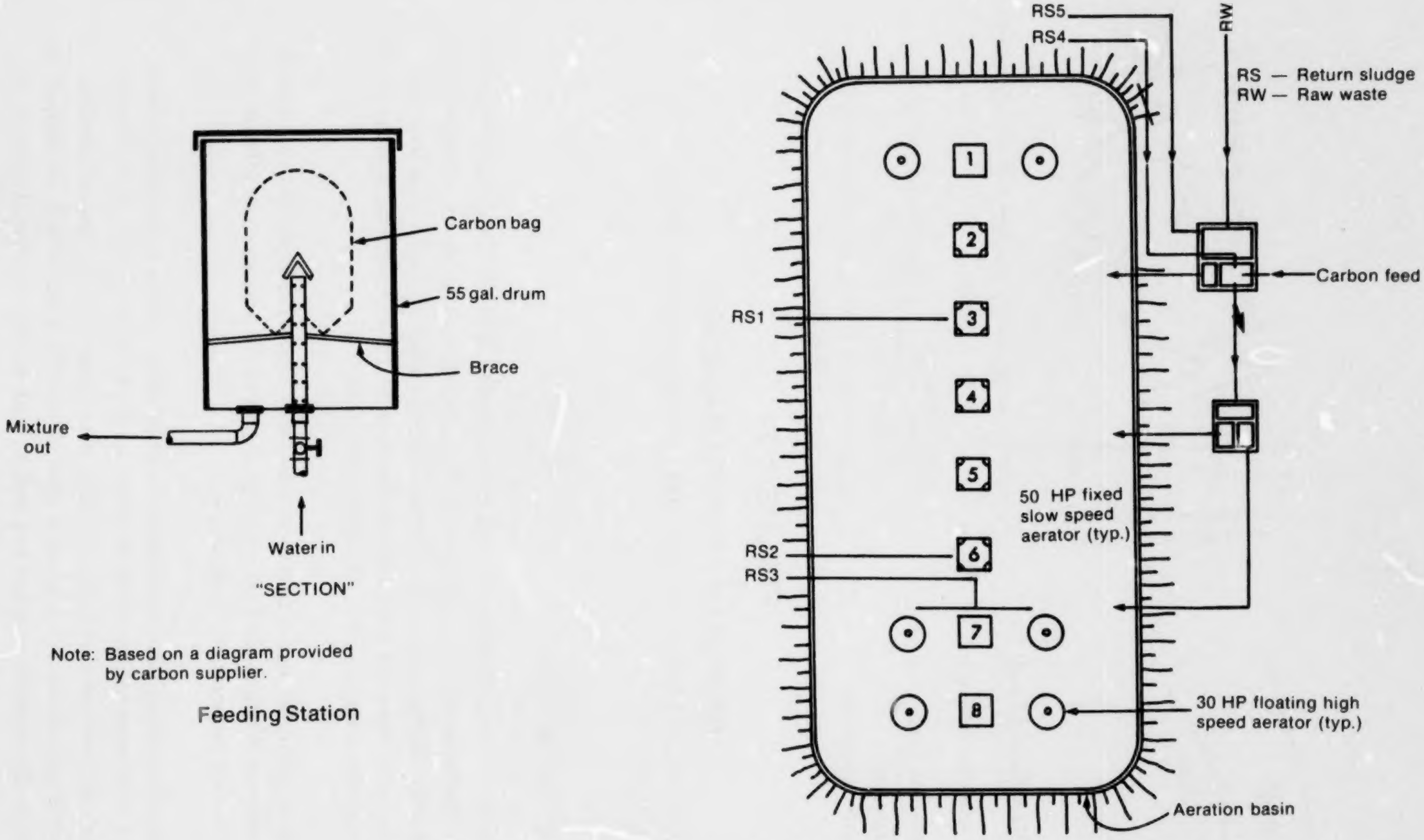
Carbon carryover to the clarifier may be difficult to settle. Chemical treatment may be required to provide effective removal of these solids. To insure effective clarification and to remove the dark, hazy appearance of the treated water, it may be necessary to provide granular media filtration.

Spent carbon can be effectively concentrated by gravity thickening and vacuum filtration or by dewatering through centrifugation. Regeneration of the carbon is best accomplished by thermal regeneration, although for small plants it is more economical to use the carbon on a throwaway basis.

TABLE 8-12

ACTIVATED CARBON CATALYST DESIGN PARAMETERS

Range of Carbon Dosages	50 to 3000 mg/l
Range of Carbon Resident Time	48 to 120 hours
Powdered Activated Carbon:	
Effective Size	2 μ
Adsorption Surface Area	750m^2/gram
Apparent Density	15.2 lb/cu ft


Carbon bag
55 gal. drum
Brace
Mixture out
Water in
"SECTION"
RS5
RS4
RW
RS — Return sludge
RW — Raw waste
Carbon feed
RS1
1
2
3
4
5
6
7
8
50 HP fixed slow speed aerator (typ.)
RS2
RS3
30 HP floating high speed aerator (typ.)
Aeration basin

Note: Based on a diagram provided by carbon supplier.

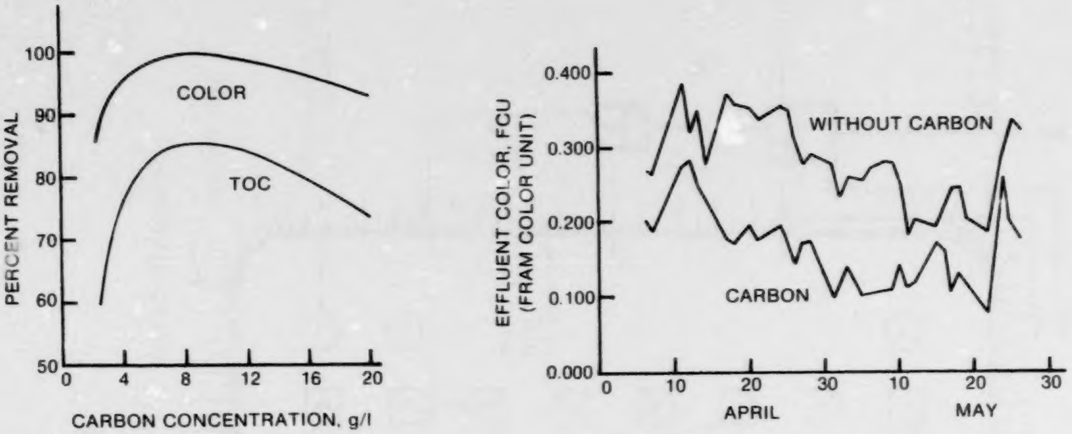
Feeding Station

Feeding Location

FIGURE 8-20

POWDERED ACTIVATED CARBON

Source: Textile Technology/Ecology Interface, 1975, Advanced Waste Treatment, Hodges and Alspaugh



Project 12090 HLO
Catalyzed Bio-Oxidation and Tertiary Treatment
of Integrated Textile Wastewaters.
EPA-660/2-74-039 June, 1974

Equilibrium Isotherms

Project 12090 HLO
Catalyzed Bio-Oxidation and Tertiary Treatment
of Integrated Textile Wastewaters.
EPA-660/2-74-039 June, 1974

Comparison of Catalyzed and Non-Catalyzed Biological Reactors

FIGURE 8-21

GRANULAR ACTIVATED CARBON

Source: Textile Technology/Ecology Interface, 1975, Advanced Waste Treatment, Hodges and Alspaugh

8.8.6 Chemical Coagulation

Chemical coagulation as a major treatment method for removal of BOD/COD is not well suited to textile wastes with the possible exception of wool processing wastewaters or when the waste stream is only partially biodegradable. The chemical process when applied as supplemental treatment before or after biological treatment will improve BOD/COD removals associated with the removal of suspended solids, a source of organic pollution.

Chemical coagulation before biological treatment may cause erratic pH levels, biomass growth, and erratic BOD removal. When applied after biological treatment, a satisfactory effluent may be produced with less expenditure of chemicals.

Coagulation is generally accomplished by adding coagulants that contain multivalent cations. These include lime, aluminum sulfate, ferric chloride, ammonia alum, potash, alum, ferrous sulfate, ferric sulfate and sodium aluminate. Addition of coagulants to the suspended solids and colloidal substances produces a floc which is allowed to settle in a clarifier. To dissipate the coagulant throughout the wastewater as fast as possible, flash mixing at point of entry to the clarifier is normally used. The correct coagulant dose for a specific wastewater and particularly the precise pH for maximum effectiveness must be determined experimentally. Polyelectrolytes are sometimes added to colloidal dispersions which are difficult to destabilize.

Chemical treatment facilities traditionally include a rapid mix basin wherein chemicals are introduced, followed by a flocculation basin, then a sedimentation tank (see Figure 8-22). In recent years the solids-contact or sludge blanket type clarifiers have become popular due to their inherent size reduction (see Figure 8-23). These units provide coagulation, settling and upward filtration in one unit. Influent wastewater is mixed with coagulants as it is fed to the center chamber where floc is formed. The floc moves to the outer chamber and rises up through a bed of previously formed floc which retains the new floc. Clear effluent flows up and out through a weir at the top of the unit. Collected sludge is periodically blown off from the bottom.

When the wastewaters contain oil and grease, the floc may be removed more effectively by the use of dissolved air flotation.

Design considerations for solids contact clarifiers are discussed in EPA's suspended solids removal manual and include:

- Provide rapid and complete mixing of chemicals, feedwater and slurry solids.
- Maximum peripheral speed of mixer blades should not exceed 5 ft./sec.
- Provide means for measuring and varying slurry concentration in contacting zone.
- Maintain sludge blanket levels a minimum of 5 feet below water surface.
- Space effluent launders to minimize horizontal movement of clarified water.

Table 8-13 presents suggested parameters for the design of a chemical coagulation system.

8.8.7 Polishing Ponds

Polishing ponds, often referred to as stabilization ponds, are used for tertiary treatment of effluents from conventional secondary biological processes, such as fixed film reactors or activated sludge. Advantages of polishing ponds are that they reduce suspended solids, oxidize organic matter, permit flow control, and wastewater storage.

Generally, polishing ponds are shallow with large surface areas. If the pond is deep (5 to 8 feet), the wastewater near the bottom is void of dissolved oxygen and anaerobic organisms may be present. Settled solids can be decomposed into inert and soluble organic matter by aerobic,

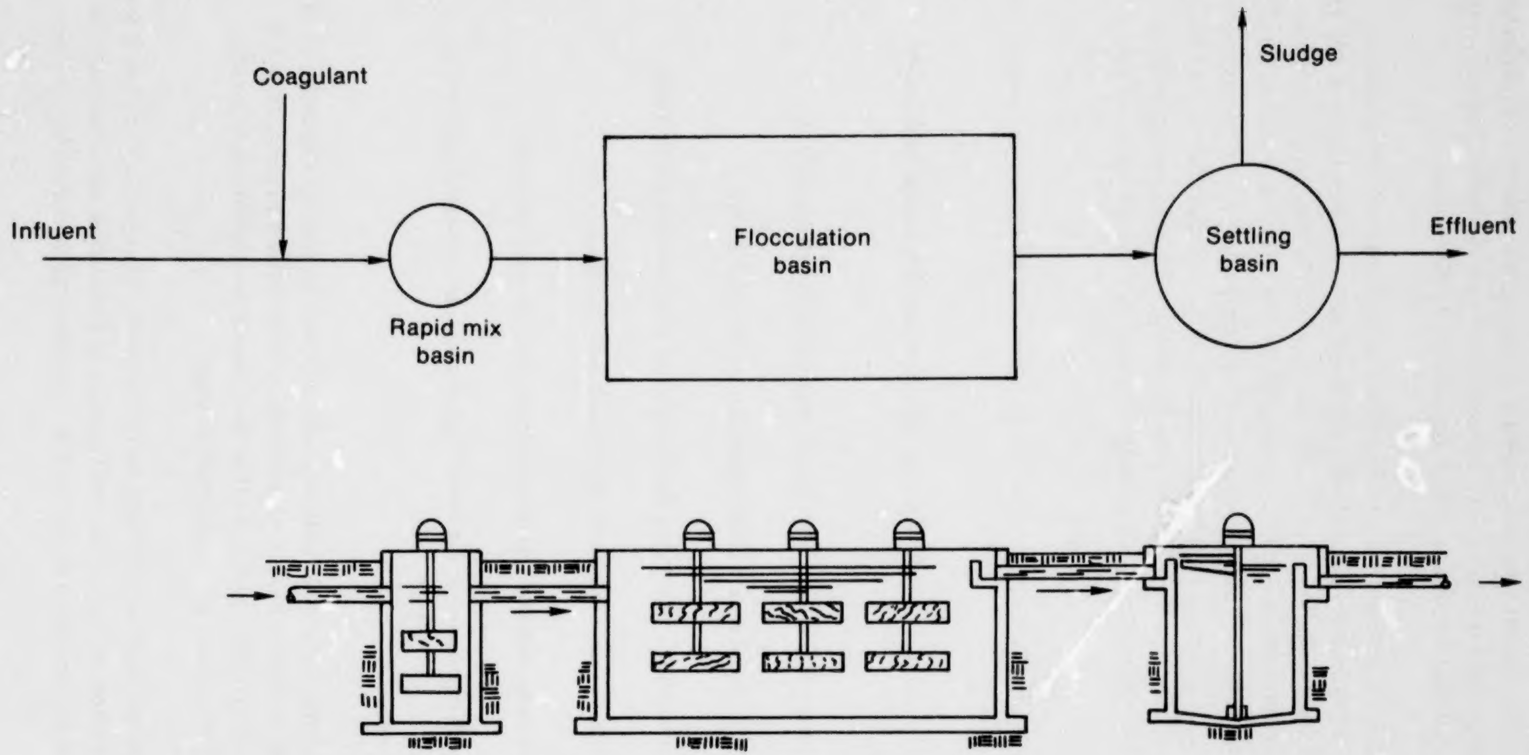

Coagulant
Influent
Rapid mix basin
Flocculation basin
Settling basin
Sludge
Effluent

FIGURE 8-22

CHEMICAL COAGULATION FLOW DIAGRAM AND SECTION

Source: Lockwood Greene Engineers, Inc.

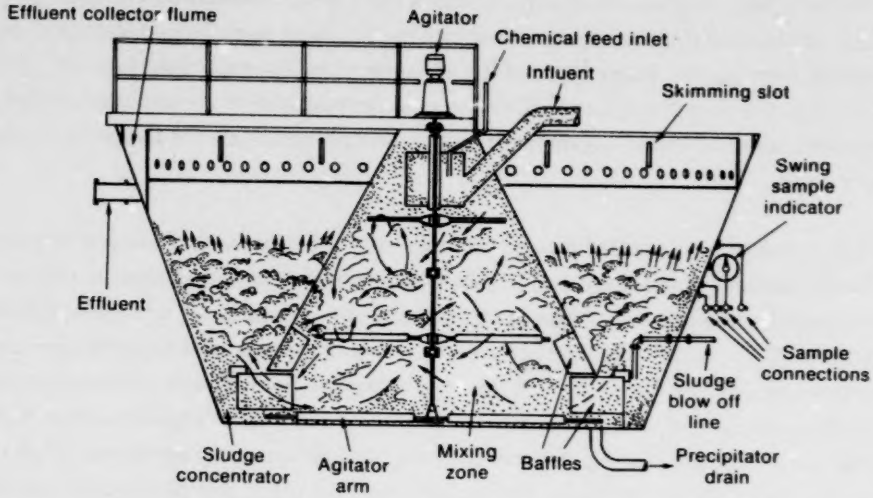

Effluent collector flume
Agitator
Chemical feed inlet
Influent
Skimming slot
Swing sample indicator
Effluent
Sample connections
Sludge blow off line
Sludge concentrator
Agitator arm
Mixing zone
Baffles
Precipitator drain

FIGURE 8-23

SOLIDS-CONTACT CLARIFIER

Source: Environmental Engineer's Handbook

TABLE 8-13

CHEMICAL COAGULATION DESIGN PARAMETERS

Rapid Mixing:	
Detention Time	30 sec. to 5 minutes
Depth	5 feet
Mixing Power (Turbine Mixers)	50 HP/1000 cu ft vol
Mixing Speed	84 to 168 rpm
Chemical Addition:	
Liquid Alum	
(Commercial Grade, 17% Al_2O_3)	300 mg/l
or Alum (as $Al_2(SO_4)_3 \cdot 18H_2O$)	300-500 mg/l
Anionic Polymer	5 mg/l
(Feed to Flocculation Zone)	
Flocculation:	
Detention Time	10 to 30 minutes
Depth	7 feet
Mixing Power (Turbine Mixers)	1.5 HP/1000 cu ft vol
Mixing Speed	12 to 37 rpm
Clarification:	
Overflow rate	300 gpd/ft^2
Depth	14 ft

anaerobic or facultative organisms, depending upon the lagoon conditions. The soluble organic matter is also decomposed by microorganisms causing the most complete oxidation. Wind action assists in carrying the upper layer of liquid (aerated by air-water interface and photosynthesis) down into the deeper portions. The anaerobic decomposition generally occurring in the bottom converts solids to liquid organics which can become nutrients for the aerobic organisms in the upper zone.

Algae growth is common in aerobic ponds; this currently is a drawback when aerobic ponds are used for final treatment. Algae may escape into the receiving waters, and algae added to receiving waters are considered a pollutant. Algae in the lagoon, however, play an important role in stabilization. Sulfates, CO_2, nitrates, phosphates, water and sunlight are used to synthesize their own cellular matter and give off free oxygen. The oxygen may be used by other microorganisms for their metabolic processes; however, when algae die, they release their organic matter in the lagoon causing a secondary loading. Ammonia disappears without the appearance of an equivalent amount of nitrite and nitrate in aerobic lagoons. From this, and the fact that aerobic lagoons tend to become anaerobic near the bottom, it appears that some denitrification is occurring.

The following tabulation illustrates suggested design parameters for polishing ponds:

TABLE 8-14

DESIGN PARAMETERS FOR POLISHING PONDS

Depth	2 to 6 (ft.)
Loading Rate	20 to 50 (lb BOD/acre/day)
Detention Time	7 to 30 (days)
BOD Removal	70 to 85 (%)

In the design of earthen ponds or lagoons there are a number of important considerations. The following were taken from State Standards and EPA publications:

8.8.7.1 Compartments

- At least two compartments of approximately equal size shall be provided.
- The compartments shall be shaped so as to preclude stagnant areas.
- Wastewater shall be fed to the cells with adequate velocities to assume self-cleansing of the distribution piping.

8.8.7.2 Distribution

- The piping and control arrangement shall be such that the individual cells may be operated in series or in parallel so as to allow complete flexibility of operation.
- The control arrangement shall be such that it is possible to maintain a different water level in each cell when operated in series.

8.8.7.3 Inlet and Outlet Structures

- Inlet structures may be designed on the basis of using weirs for distributing and measuring flows to the cells.
- Steel, concrete or other durable material should be used in all portions of the control devices.

8.8.7.4 Inlets

- Inlets to the cells must be so designed as to eliminate erosion of the cell bottom.
- Inlets shall be located so as to prevent short-circuiting.

8.8.7.5 Outlet Structures

- Outlet structures should generally utilize weirs for liquid level control.
- A portion of the outlet structure must act as a scum baffle, unless separate scum baffles are provided.
- Weirs and control devices should be aluminum or fiberglass.
- Outlet structures shall provide means for complete drainage of the cells.

8.8.7.6 Transfer Pipes

- Provide seepage collars near midpoint.
- Provide fiberglass plugs to close transfer pipes.

8.8.7.7 Operating Level

- Stabilization ponds shall be designed to normally operate within overall depths of three feet minimum to five feet maximum.

8.8.7.8 Construction

- Dikes shall either be constructed of relatively impermeable material or be lined with suitable liners.
- The top of the dikes shall be a minimum of 12 feet wide to provide access for maintenance equipment.

- Dike corners shall have radii such that maintenance equipment will have complete freedom of movement over all portions of the dikes.
- In general interior slopes should be a minimum of 3:1 and exterior slopes should be a minimum of 2:1.
- All slopes on dikes shall be protected from erosion. Protection against erosion shall extend one foot below minimum water surface and one foot above maximum water surface.
- Stabilization ponds shall have a minimum freeboard of two feet.
- Stabilization ponds shall be so constructed as to minimize percolation through the bottom.
- The stabilization pond area shall be enclosed with a suitable fence to exclude livestock and discourage trespassing. A vehicle access gate of sufficient width to accommodate maintenance equipment shall be provided.

8.9 Oil and Grease Reduction

Oil and grease reduction methods are dependent upon the form in which the oil is present in the waste stream. That is, free oils or grease are removed by flotation, centrifugation or gravity separators. Where free floating oil is encountered, it can be removed by directing the flow into a basin having a retention period of 30 minutes to 1 hour and a velocity not greater than 2 fpm. Oil collected at the surface is skimmed off using a rotating half pipe, top scraper mechanism, rotary blade mechanism, etc. Information on the design of gravity separators is provided by the American Petroleum Institute. When oil and grease are introduced into the waste stream by scouring with non-biodegradable detergents, an oil-in-water emulsion is formed. This emulsion cannot be effectively treated in a biological system. Reduction of these oils will require emulsion breaking using acid cracking, chemical coagulation or de-emulsifying agents. One knit fabric finishing mill pilot tested the use of ultrafiltration for separating and concentrating waste knitting oils. The pilot system operated at a flux rate of 60 gpd per square foot at 200 psig and temperatures of 77° F. Initial results were not encouraging due to fouling of the membrane. Other membranes are being investigated.

8.10 Chrome Removal

Chromium is used for oxidation in some cotton and rayon dyeing and for chemical fixation in wool dyeing. Usually, sodium dichromate, the hexavalent or oxidized form of chromium, is used, and a small percentage of chromic (trivalent) chromium is produced on reduction. The hexavalent form is yellow and soluble at all pH's, while the trivalent form is greenish and insoluble at pH's above 6.5.

In cotton and synthetic dyeing, other oxidants (air, hydrogen peroxide, peroxy acids and their salts) may be used in place of the chromate, and complete chromium removal may be obtained. In wool dyeing, excessive chrome add-ons are often used. A considerable reduction in effluent chromium concentrations may be obtained by reducing the add-ons.

Concentrations of chromates used in dyeing are not expected to significantly reduce the efficiency of the activated sludge process, but may affect anaerobic sludge digestion.

When in-plant removal is not possible, removal of chromium is best accomplished on segregated waste streams by chemical treatment. Chromium as hexavalent chrome (Cr^{+6}) is toxic. It is removed by reduction to its trivalent form (Cr^{+3}) which is less toxic by a factor of about 100. After reduction, the trivalent chrome may be precipitated as the hydroxide and removed as a sludge. The effluent is introduced into the mill wastewater treatment plant.

The reduction of chrome is pH dependent, at lower pH (less than 4) requires less retention time. Sulfur dioxide (SO_2) is generally used as a reducing agent though other chemicals such as ferrous sulfate ($FeSO_4$) and sodium metabisulfite ($Na_2S_2O_5$) have also been used.

Precipitation reactions are also pH dependent with pH 9 as the optimum. Hydroxide sources used for precipitation are generally sodium hydroxide (NaOH) or lime.

The treatment process may be best suited to a batch type system when the daily volume is less than approximately 50,000 gallons. Two tanks each with one day's flow are used. Continuous treatment will require a reaction tank, pH adjustment tank, and a settling tank (see Figure 8-24).

Suggested design parameters are given in the following Table:

TABLE 8-15
CHROMIUM REMOVAL DESIGN PARAMETERS

Reduction pH	—	<3
Precipitation pH	—	8.0 to 9.9
Flocculation Time	—	20 minutes
Clarifier Overflow Rate	—	<500 gal/day/sq. ft.
Clarifier Depth	—	10 to 12 feet
Sludge concentration	—	1-2% by weight

The continuous chrome reduction process requires instrumentation and control. The reduction tank should be controlled using pH and ORP (oxidation reduction potential); the adjustment tank requires pH control.

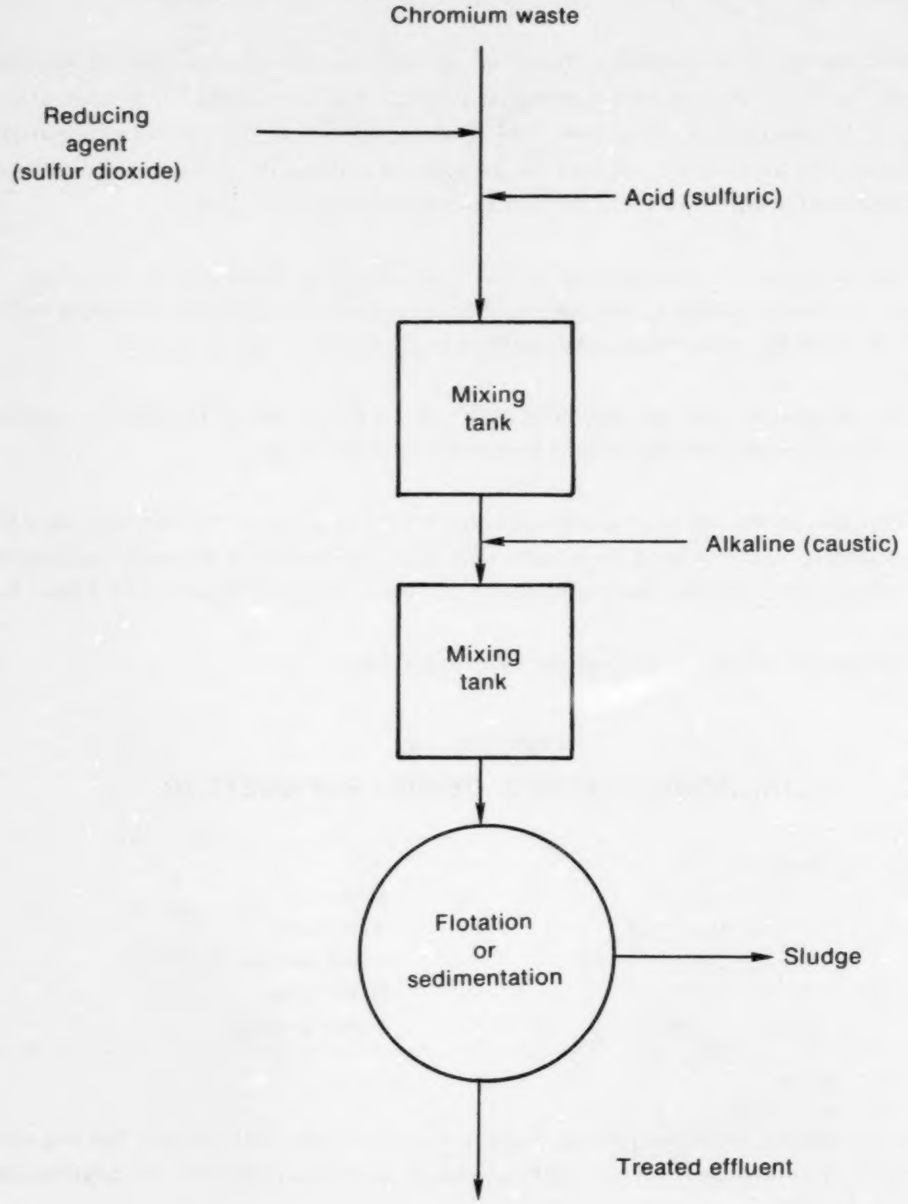

Chromium waste
Reducing agent (sulfur dioxide)
Acid (sulfuric)
Mixing tank
Alkaline (caustic)
Mixing tank
Flotation or sedimentation
Sludge
Treated effluent

FIGURE 8-24

CHROMIUM REMOVAL PROCESS

Source: Lockwood Greene Engineers, Inc.

8.11 Color Removal

Color is found in wastewater throughout the textile industry. Some colors are water soluble and some are not (dispersed and vat dyes). Biodegradability is highly variable. Many hues are used in dyeing, and may appear in wastes; their combination in waste streams frequently generates a gray or black color. Since color chemicals are specifically formulated for resistance to degradation under the oxidizing conditions of the world, it is not surprising that removal of color in an aerobic biological system is erratic. Activated sludge systems can generally remove about 50 to 90% of the color.

When color removal is required, all in-plant means of reducing the color in the waste must be used. This may involve the following:

- Segregate all waste print pastes, if any, and dispose of separately in landfill, ocean or incinerator.
- Reduce losses in the color shop by careful hand cleaning of all brushes, troughs, doctor blades, cans, tanks, and screens.
- Attempt to get weaving mills to reduce the use of fugitive tints in weaving.
- Try to exhaust the dyes more thoroughly in the dye process.
- Use dye processes that cause less color loss; for example, solvent, pad-and-stream, microfoam, methanol, and ammonia dyeing.

Following this, only the concentrated color wastes should be segregated and treated, as this may possibly produce enough color removal to satisfy the requirements. This will usually involve the exhausted-dye baths and the color-shop wastes (cleanup, wash after printing and blanket wash).

Color removal technology at present includes the use of chemical coagulation and/or carbon adsorption. See following sections 8.11.1 and 8.11.2. Generally water insoluble dyes can be handled by chemical coagulation while soluble dyes require carbon adsorption. Some wastewaters may require both processes. A recent study conducted at North Carolina Wastewater Research Center, (co-sponsored by ADMI and EPA) investigated the best methods of decolorization by dye class using coagulation and adsorption. The results of this study is described in Table 8-16.

Additional color removal methods under investigation are the use of ozone and hyperfiltration. A few years ago photodegradation was investigated but was found to require many weeks of exposure.

TABLE 8-16

COAGULATION AND ADSORPTION: BEST MEANS OF DECOLORIZATION BY DYE CLASS

Dye Class	Dyeing no.	Substrate	Best Treatment	Requisite Chemical Dosage,* mg/l as Al or mg/l of PAC	Initial ADMI color value	Final color value	Initial TOC, mg/l	Final TOC, mg/l	% TOC reduction
Vat	1	Cotton	Alum coagulation	80	1910	140	265	115	57
Disperse	3	Polyester	Alum coagulation	60	315	45	300	170	43
Disperse	6	Polyamide carpet	Alum coagulation	30	100	50	130	110	15
Disperse	9	Polyester carpet	Alum coagulation	160	315	80	240	115	52
Disperse	14	Polyester	Alum coagulation	60	1245	230	360	130	64
Vat + Disperse	17	Polyester/cotton	Alum coagulation	50	1100	80	350	300	14
Sulfur	15	Cotton	Alum coagulation	8	1450	80	400	345	14
Reactive	5	Cotton	PAC**	2500	3890	25	150	20	87
Reactive	16	Cotton	PAC	1700	1390	50	230	140	39
Basic	8	Polyacrylic	PAC	1000	12000	100	255	140	45
Basic	18	Polyester	PAC	400	2040	100	1120	800	29
Acid	10	Polyamide	PAC	1000	4000	260	315	175	44
Azoic	20	Cotton	PAC	800	2415	100	170	135	21
1:2 metal complex	2	Polyamide	PAC	900	370	100	400	325	19

*Different grades of PAC were evaluated, including Darco KB, HDB, HD-3000 and Nuchar D-14, D-16, at a variety of pH values. Data for the best overall treatment achieved are reported here. Alum dosages are reported for pH 5-6 where best treatment was achieved.

**Powdered Activated Carbon

SOURCE: University of North Carolina Department of Environmental Sciences and Engineering, from ESE Notes, Vol. 12, No. 2, March 1976.

8.11.1 Chemical Precipation

Color removal of dispersed, vat, and sulfur dyes is well suited to chemical treatment. Coagulants such as alum and ferric sulfate applied at approximately 300 to 600 mg/1 or lime at approximately 300 to 600 mg/l will remove 75 to 90% of the color. In addition to the quantity of chemical required, significant consideration in the selection of coagulant to be used are the characteristics of sludge produced. Alum sludge is generally most voluminous; ferric sulfate produces a sludge with less volume than alum but larger than lime. Lime sludge settles fast and can be thickened to the highest concentration. In addition, lime sludge dewaters easily on a vacuum filter.

The results of laboratory scale pilot plant studies on chemical coagulation of dye wastes were reported by Souther and Alspaugh of Cone Mills Corporation (17). The pilot plant consisted of waste storage, rapid mixing, flocculation, and 2-hour sedimentation. Chemicals were fed on a continuous basis. The findings of this study are illustrated in Table 8-17.

TABLE 8-17

TREATMENT OF TEXTILE DYE WASTES BY CHEMICAL COAGULATION

Waste	Coagulant Chemicals	Dosage ppm	pH		BOD Initial	Color Initial	Removals %	
			Initial	Final			BOD	Color
A	$FeSO_4$ Lime*	700 700	10.2	10.2	1028	40000	41.5	91.0
A	Alum H_2SO_4	2510 780	10.2	6.0	1028	40000	42.7	97.5
A	$CaCl_2$	2950	10.2	8.4	1028	40000	42.5	85
B	$FeSO_4$	700	11.0	10.2	—	—	42.5	80
B	$FeSO_4$ Lime*	490 490	11.0	11.0	—	—	52.5	80
B	Alum H_2SO_4	2000 800	11.0	5.7	—	—	56.9	90
B	$CaCl_2$	900	11.0	10.8	—	—	49.0	84

Waste A — Waste water from sulfur and indigo dye mill
Note: 14 days storage in lagoon effected no observable reduction in color

Waste B — Waste water from vat, sulfur, and indigo dyeing and finishing mill

* High calcium hydrate $Ca(OH)_2$

Representative value.

8.11.2 Activated Carbon Adsorption

8.11.2.1 Carbon Characteristics

Granular activated carbon can be manufactured using a number of source materials, including bituminous coal, coconut shells, and pulp mill black ash. The surface area of a pound of granular carbon is equal to 125 acres, thus illustrating the magnitude of the porosity involved.

When a wastewater containing organic chemicals passes through a bed of carbon, the chemical molecules come in contact with the surface of the carbon and are held there by weak physical forces called Van de Waals forces. The water continues through the bed, with a reduced concentration of organic contaminants.

It is important to note when there is a mixture of organic molecules present, adsorption selectivity becomes a prime factor in the efficiency of the unit process. That is, carbon will preferentially adsorb some organic molecules over others. This selectivity is governed by three properties of the molecules: molecular structure, molecular weight, and molecular polarity. For example, if a wastewater contains a combination of an organic dye and a solvent, the dye, being a larger compound with a higher molecular weight than the solvent, would be more readily adsorbed by the carbon; therefore, there is a lack of correlation between the initial color value and the required carbon dosage. Activated carbon adsorption is generally effective in decolorizing reactive, basic, acid, azoic, and 1:2 metal complex dyeing wastewaters.

8.11.2.2 Adsorption Feasibility

An adsorption isotherm is usually run on representative samples of wastewater to determine the feasibility of using granular carbon to remove the organics. This test is a very useful tool in determining the feasibility of carbon treatment. (See Table 8-18 for isotherm results from tests on textile wastewater.) The dosages from an isotherm may be very conservative, since they do not include the effects of biological degradation of organics during treatment.

An adsorption isotherm will provide the following useful information:

- Adsorbability
- Weight pickup
- Degree of removal
- Sensitivity to containment
- Effect of variables such as pH, temperature, etc.

TABLE 8-18

TEXTILE INDUSTRY WASTEWATER SURVEY SUMMARY OF ADSORPTION ISOTHERM RESULTS

	Untreated Wastewater		Following Filtration		Following Adsorption		Organic Reduction (%)	
	Range	Median	Range	Median	Range	Median	Range	Median
TOC	9-4670	290	9-3335	183	1-440	16	75-99	94
Color	(OD) 0.02-5.40	0.56	0.02-1.64	0.29	0.005-0.09	0.01	78-100	98
	(APHA) 50-7000	450	0.3-3500	410	0-15	0	98-100	100

*OD — Optical Density

**APHA — American Public Health Association

Source: Calgon Corporation. From Experience with Granular Activated Carbon In Treatment of Textile Industry Wastewaters, EPA Seminar, Atlanta Ga., September 1973.

8.11.2.3 Pilot Carbon-Column Tests

The purpose of pilot tests is to obtain operating and design information. The test which should be carried out in conjunction with pretreatment studies involves passing a side stream to four columns filled with granular carbon and connected in series. The data obtained from the pilot column study tests indicate:

- The effect of biological activity
- Performance under dynamic conditions
- Filtration characteristics
- Contact time necessary to accomplish objectives

8.11.2.4 Pretreatment Requirements

It sometimes becomes necessary to treat wastewater prior to adsorption. Suspended solids content above 50 mg/1, for instance, would collect in the carbon bed and create excessive head loss across the bed. Lint can also cause premature pressure drop and problems by clogging pumps and valves. General practices employed for suspended solids or lint removal are screening devices, sand filters, diatomaceous earth filters, or conventional clarifiers. Adjustments in pH might also be necessary to destabilize colloidal materials or to optimize the adsorption process.

8.11.2.5 Adsorbers

Either pressure vessels or common wall concrete containers may be employed to house the carbon. The choice of adsorber types will be based on economics, land availability, and the amount of suspended solids present in the influent to the adsorption system.

These adsorbers are similar in design to rapid sand filters found in potable water plants. Water may be percolated through these adsorbers either upflow or downflow at surface loading rates anywhere up to 10 to 12 gpm/ft^2.

Adsorption systems configurations fall into four basic categories:

- Moving beds
- Fixed beds in series
- Fixed beds in parallel
- Expanded beds

8.11.2.6 Carbon Usage and Thermal Reactivation

When activated carbon has become exhausted, three available alternatives may be considered:

- Throw the exhausted carbon away
- Thermally reactivate the carbon to its virgin quality and reuse it
- Have another company pick up the exhausted carbon and reactivate it for you (custom reactivation)

The method chosen is usually a matter of economics. Naturally, the most expensive method would be to employ the carbon on a throwaway basis. This method is usually reserved for the very small adsorption systems in which the carbon exhaustion rate is extremely low. When carbon usage rate reaches 400 lbs/day thermal regeneration may be economical.

If the choice is made to reactivate the carbon, then thermal regeneration equipment must be designed and installed based on the carbon exhaustion rate. Normally, 30 to 50% extra capacity is designed into the thermal-reactivation unit, since the increase in costs is not significantly greater than a unit sized to handle the specific exhaustion rate that was determined through testing. Figure 8-25 illustrates a typical reactivation system.

Both multiple-hearth furnaces and rotary kilns have been employed for thermal regeneration of the carbon. Since thermal reactivation equipment is a significant portion of the capital investment, individuals may consider having someone else thermally reactivate their carbon. This approach to reactivation is usually chosen by those persons who do not want to reactivate the carbon themselves or to expend the capital required to purchase a thermal-reactivation unit.

8.11.2.7 Biological Reactivation

Spent carbon granules can be subjected to a virile aerobic biological culture that desorbs and bio-oxidizes the desorbed matter, thereby reactivating the carbon.

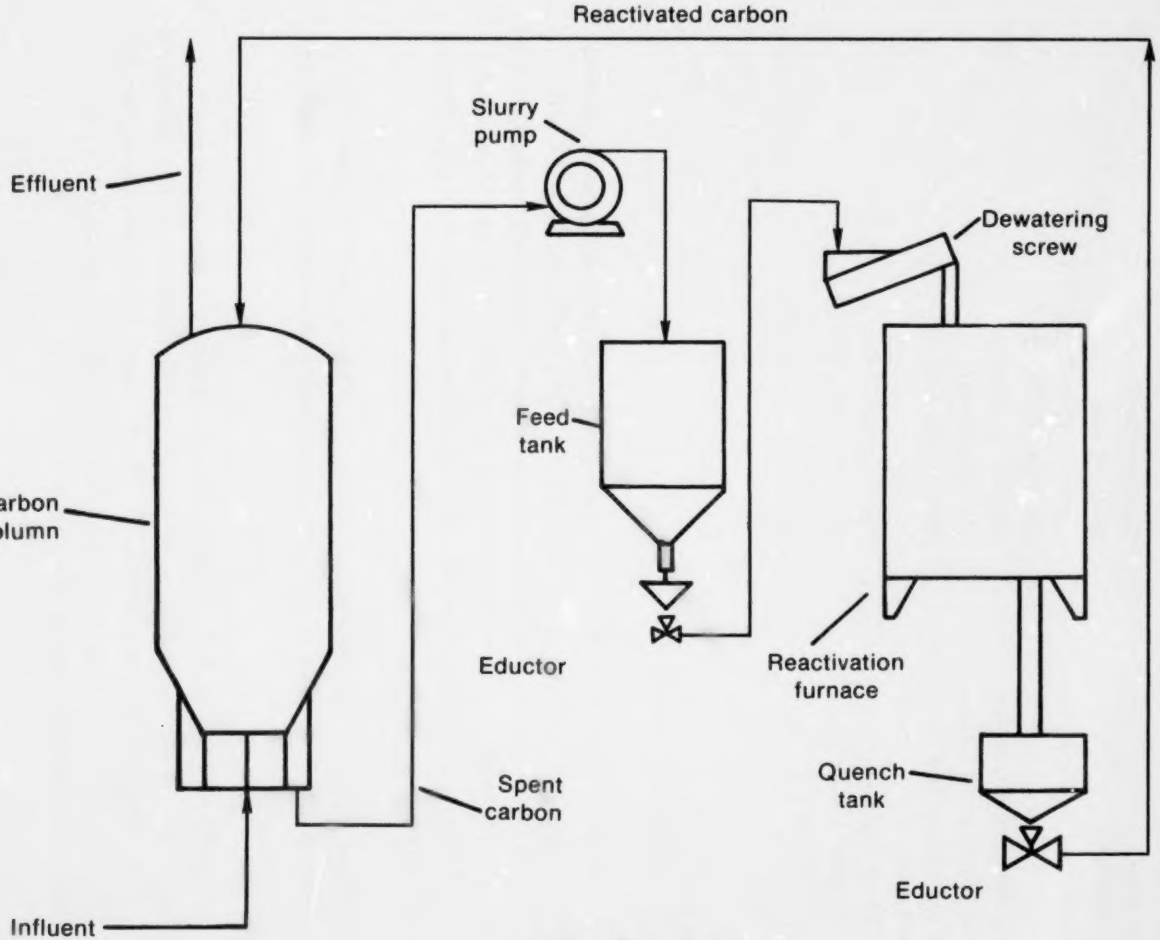

Reactivated carbon
Slurry pump
Effluent
Dewatering screw
Feed tank
Carbon column
Eductor
Reactivation furnace
Quench tank
Spent carbon
Eductor
Influent

FIGURE 8-25

CARBON ADSORPTION SYSTEM

Source: Lockwood Greene Engineers, Inc.

TABLE 8-19
ACTIVATED CARBON ADSORPTION DESIGN PARAMETERS

System Types:	Fixed Beds (Series or Parallel) Moving Beds Expanded Beds
Mesh Carbon	8 x 30, 12 x 30 to 12 x 40
Flow Rate	5 to 15 gpm/sq. ft.
Contact Time	45 to 75 min.
Column Bed Dimensions:	Depth — 10 to 30 ft. Diameter — 4 to 20 ft.
pH of Regenerant Liquor	Maintain 6.5 to 8.0
DO of Regenerant Liquor	Maintain 2 mg/l
Bed Backwash Rate	20 to 30 gpm/sq. ft.
Reactivation:	
Temperature	1600° to 1800° F.
Furnace Loading	50 to 100 lb/sq. ft./day
Carbon Loss	2 to 10%

8.11.3 Synthetic Resin Adsorption

Synthetic resins are used to remove refractory organic matter (soluble color, phenols, surfactants and dissolved metals) from wastewaters. The resins can be regenerated for reuse with dilute alkali (2% NaOH) or solvents (methanol). Adsorbent resins and granular carbon are used in a similar way. Resins exhibit a higher adsorption rate than carbon, thus permitting smaller equipment sizes. Columns of different types of resins can be arranged in series for the removal of different specific classes of dyes and the system can be automated.

Regeneration may be keyed to effluent color or a timer. Tests at one textile finishing mill required regeneration after 7 to 10 days. The spent caustic soda is neutralized with a sulfuric acid rinse.

When methanol is used for regeneration, the spent dyes can be distilled, condensed and recovered and disposed of by thermal oxidation. Indications are that synthetic resins can remove approximately 90% color, 60% COD and 40% BOD. The life expectancy of caustic-regenerable resins is about 3 to 5 years, and methanol-regenerable resins could last indefinitely (18). Figure 8-26 represents a typical resin adsorption system.

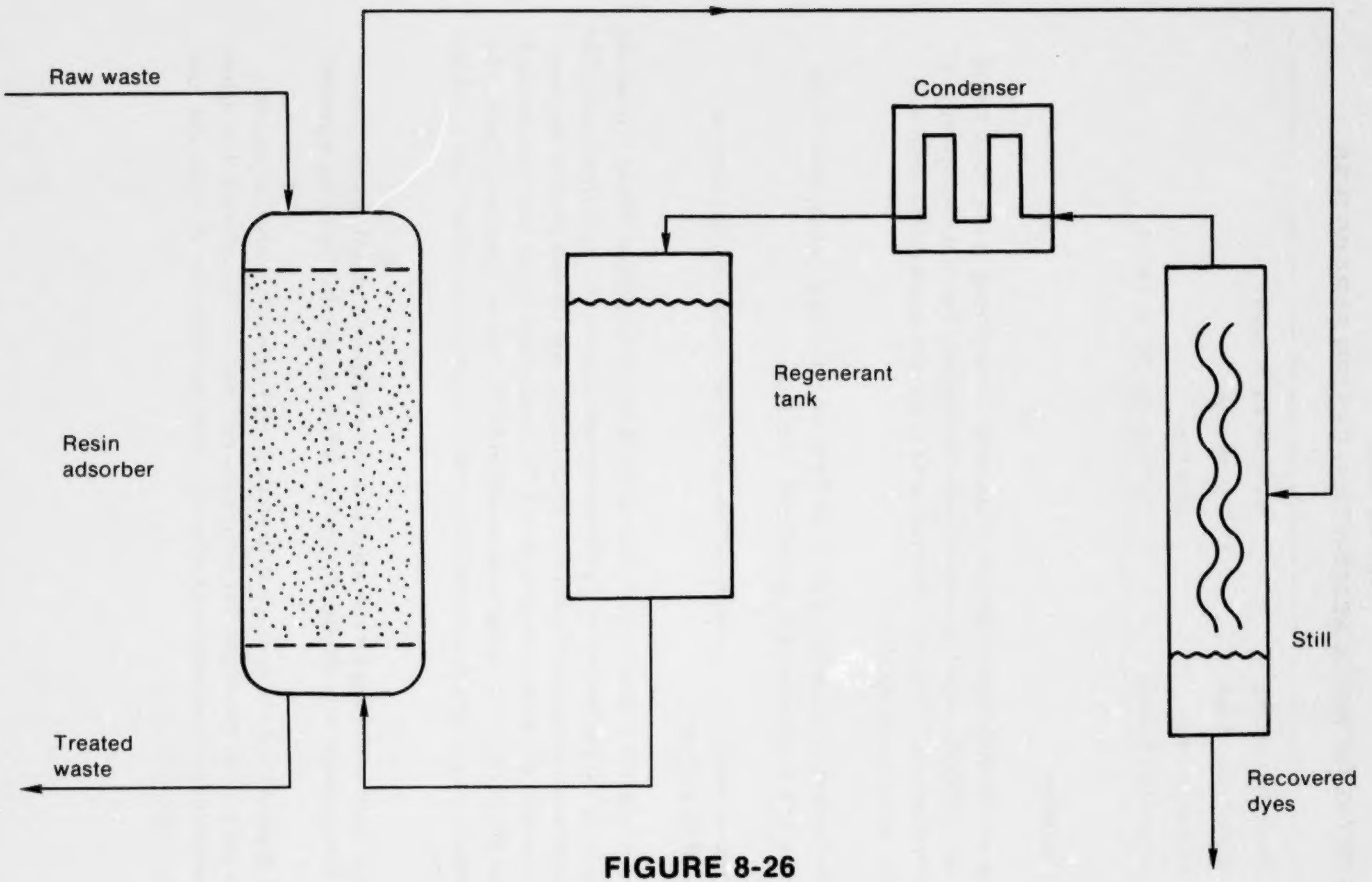

Raw waste
Condenser
Resin
adsorber
Regenerant
tank
Still
Treated
waste
Recovered
dyes

FIGURE 8-26

RESIN ADSORPTION SYSTEM

Source: Lockwood Greene Engineers, Inc.

TABLE 8-20
SYNTHETIC RESIN ADSORPTION DESIGN PARAMETERS

Hydraulic Loading	1-2 GMP/cu. ft. resin
Regeneration Time	7 to 10 days
Backwash Rate	10 x Flow
Regenerant Dosage	2% NaOH @ 130° to 140° F.

8.11.4 Ozonation

Research work at a finishing mill revealed successful color removal using ozone. It was found necessary to use a multiple contact (2-stage) process. Substantially less ozone is required at a pH of 5.0 rather than at 6.5. Little COD decrease or BOD increase was found to occur with low ozone dose and contact time (16).

Based upon the previously mentioned work at the Wastewater Research Center, ozone treatment is effective with reactive dyes but not with disperse dyes.

Additional work on samples from a carpet mill revealed an 80% color reduction using an ozone dosage of 15 mg/l (19).

Because ozone is unstable, it must be produced on site; it cannot be shipped. Ozone is produced by passing dry air or oxygen between two plates connected to an alternating current source. The process produces ozone as a mixture with either air or oxygen, and the exit gas from the ozonator typically contains 1% ozone from air feed or 1.7% ozone using oxygen feed. The ozonized gas can then be dispersed into the water to be treated either by various injection methods or by forcing the pressurized gas through a porous diffuser at the bottom of a contact tank or column (see Figure 8-27).

In one method, ozone containing gas and water mixes in a specially designed positive pressure injector and flows concurrently through the system before the gas and liquid are separated.

Ozonation of dispersed, metallic dyes and their aromatic dye carriers and additives appears practical with and without the conjunctive use of exchange resins or lime addition. Laboratory studies were successful in deodorization of sulfur dye waste and reduction of copper and color in metallic dye wastewaters (20).

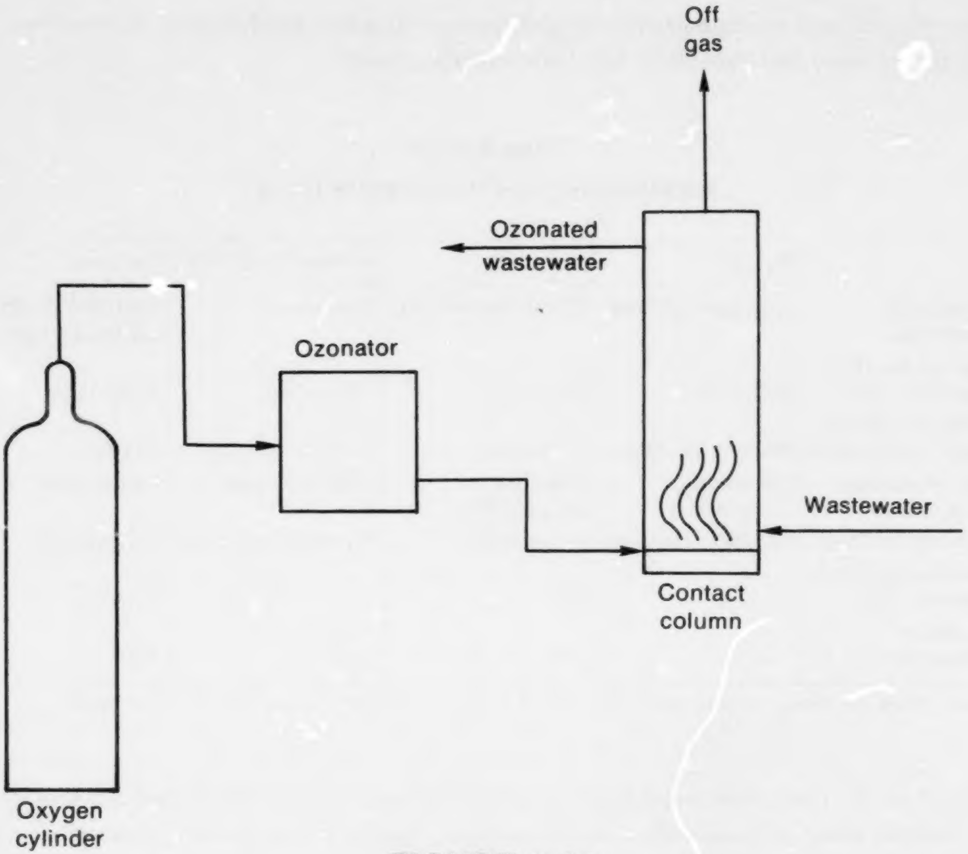

Off gas
Ozonated wastewater
Ozonator
Wastewater
Contact column
Oxygen cylinder

FIGURE 8-27

OZONE TREATMENT SYSTEM

Source: Lockwood Greene Engineers, Inc.

8.11.5 Hyperfiltration

Hyperfiltration (reverse osmosis) involves the filtering of aqueous solutions by membranes or hollow fibers with fluxrates of 5 to 50 gpd per square foot at 350 to 1000 psig. The system is capable of removing substantial fractions of dissolved impurities, including organic and inorganic material.

There are four basic configurations of hyperfiltration available: spiral, tubular, hollow-fine fiber and dynamic. See Table 8-21 for characteristics of each.

TABLE 8-21
MEMBRANE CHARACTERISTICS

	Spiral	Tubular	Hollow-Fine Fiber	Dynamic
Membrane Material	Cellulose acetate	Cellulose acetate	Polyamide	Hydrous Zr (IV) oxide-polyacrylate
Production Rate gal/ft^3 - day	500-7500	100-1500	200-15000	1500-15000
Method of Membrane Replacement	Module (on-site)	Tubes (on-site)	Module (on-site)	In-situ
High Pressure Limitation	Membrane compaction	Membrane compaction	Fiber collapse	No problem
Particles in Feed	Filtration required	No problem	Filtration required	No problem
Permissible Feed Range, pH	5.5-7.5	5.5-7.5	2-10	4-11
Maximum Temperature, F°	100	100	100	200

Source: Textile Technology/Ecology Interface, 1975, Recycle of Textile Wastewaters, Brandon and Porter.

A recent on-site pilot plant investigation (under EPA Grant # S-800929) (16) at a 2 mgd dyeing and finishing plant indicates color removal of approximately 99% and water recovery of up to 90%. It was found that batch dyehouse discharges need only be filtered through 25 micron and 1 micron cartridge filters in series before passage through hyperfiltration membranes. Temperature and pH were controlled per the manufacturers recommendations. For a summary of the study's performance see Table 8-22.

The results of this study indicated that hyperfiltration is capable of renovating composite dyeing and finishing plant wastewater such that the purified water and concentrated waste dyes may be reused in production dyeing. Though the results of this work have been encouraging, additional work will be necessary to establish the process fully. Figure 8-28 illustrates a typical hyperfiltration and recovery system.

TABLE 8-22

SUMMARY OF PERFORMANCE OF HYPERFILTRATION MODULES IN DEMONSTRATION PILOT PLANT[1]

Manufacturers:	Westinghouse	Dupont	Gulf[2]	Selas Flotronics
Membrane:	Cellulose	Polyamide	Cellulose Acetate	Zr (IV) - PAA
Configuration:	internal tubular	hollow-fine fiber	spiral wound	externally coated tube bundle
Test Date:	12/73 - 1/74	2/74 - 3/74	4/74	6/74 - 7/74
Hours of Test:	1059	187	804	944
Test Conditions:				
Pre-filtration	25-micron cartridges	D.E.[3]	25-micron cartridges	250-micron screen
pH	5.6 - 7.0	6.2 - 8.3	5.8 - 7.0	6.6 - 8.5
Temperature, °F	55 - 90	52 - 90	59 - 78	68 - 195
Pressure, psi	300 - 450	350	400	350 - 1050
Average Rejection, % Total Solids	95	95	96	90
Color	99+	99+	99+	98+
Conductivity	92	94	95	85
COD	96	92	94	95

[1] Total plant composite and dyehouse (only) wastewaters used in this study.

[2] Now ROGA, a Division of U.O.P., Inc.

[3] Diatomaceous earth - swimming pool filter - preceded 25-micron and 1-micron cartridge filter.

Source: Textile Technology/Ecology Interface, 1975, Recycle of Textile Wastewaters, Brandon and Porter.

8.12 Other Pollutants Removal

8.12.1 Phenolics

Phenolics in the wastewater indicate the use of chemical compounds containing the phenol structure. Low concentrations in the parts-per-billion range may cause off-tastes in drinking water after chlorination or in fish. Many process chemicals, including some detergents, have this structure as part of the molecule, but the major sources are probably the orthophenylphenol used as a dye carrier and the phenol-formaldehyde resin used for final finishing. The only discharge from the final finishing process is the excess solution left in the pad or impregnating trough. This should never be dumped to waste. It may be sprayed on the wastepaper or wood collected in the mill and incinerated.

Activated sludge will oxidize most of the phenolics if the associated chemical structure is not too complicated, but the rigorous treated-effluent guideline concentrations may still be exceeded. When this happens, a process-chemical survey may reveal the probable source, and treatment

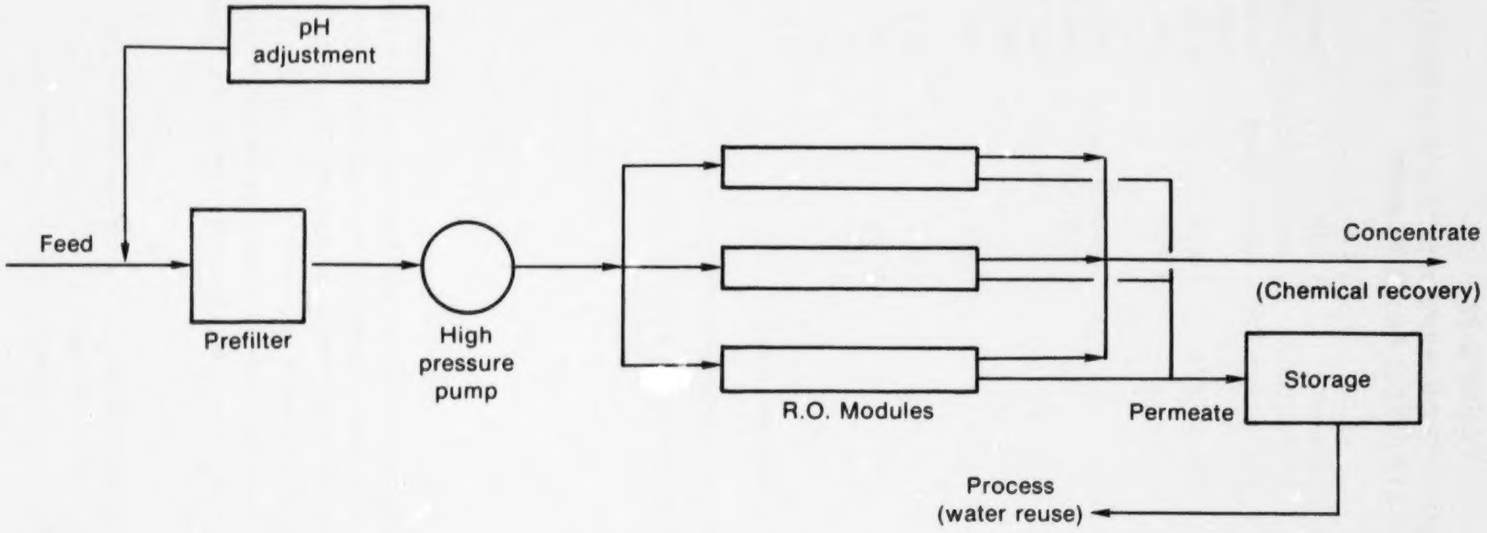

pH adjustment
Feed
Prefilter
High pressure pump
R.O. Modules
Concentrate
(Chemical recovery)
Storage
Permeate
Process (water reuse)

FIGURE 8-28

HYPERFILTRATION (REVERSE OSMOSIS) TREATMENT SYSTEM

Source: Lockwood Greene Engineers, Inc.

or process-chemical substitution should involve the point of origin. Chemical coagulation, oxidation with potassium permanganate or physical adsorption may be useful in removing these compounds.

8.12.2 Metals

Metals enter the waste stream from mordants, metallized dyes, dye oxidants, catalysts for resin treatment, acid fulling, sizing preservatives and impurities found in common chemicals. Copper, zinc and chromium are normally used at low levels in textile processing. These are concentrated in the activated sludge at 20 to 100 times the influent concentrations. Acidic pH's may cause some bacterial kills, since dissolved metallic ions are more toxic than the insoluble metallic hydroxides and carbonates normally present. Of particular concern are the so called toxic metals, whose discharge to the receiving waters may be limited. In general, most metals do not have serious effects in biological waste treatment systems, provided the pH is maintained in the range of 8 or above. Under such conditions the metals are precipitated as the hydroxides become incorporated in the sludge, and the amount of metal that can exist in ionic form is negligible. The presence of the precipitated hydroxides, however, constitutes a serious threat. If the pH should fall, large amounts of metals in the ionic form could be released and cause great harm to the treatment plant and stream biota. Mercury is an exception and should be recognized. It should be removed at the source by isolation and separate treatment.

8.12.3 Sulfide

Sulfide usage in textile processing is very low, and sulfide is occasionally present in mill wastes. If present, the pH should be kept in the alkaline region of 9 to 10 to prevent the volatilization of the very odorous hydrogen sulfide. The activated-sludge process will readily oxidize sulfide to sulfate. Generally, the presence of sulfide will be no problem. The major source of trouble will be production of sulfide odors in the lateral lines to the sewage plant if acidic pH's are produced by other wastes in the system. If desired, sulfide may be oxidized by hydrogen peroxide, chlorine, hypochlorite or potassium permanganate.

8.12.4 Detergents (MBAS, ABS, LAS)

Detergents are usually measured by the methylene-blue active substances (MBAS) and may be composed of alkyl benzene sulfonates (ABS), normally considered as nonbiodegradable, and linear alkyl sulfonates (LAS), normally considered as biodegradable. The nondegradable ABS compounds are no longer manufactured for general detergent use, but they may be used in some textile operations in which a considerable portion may pass through the activated-sludge treatment process. When reductions are required, the most practical way is to trace the source (e.g., through a process-chemical inventory survey) and to eliminate its use by substituting a biodegradable LAS detergent or even soap.

8.12.5 Phosphate

In some instances, phosphate removal may be required. If so, it may be more readily done by substituting nonphosphate chemicals such as ethylene-diaminete-triacetic acid (EDTA) and others for the phosphates normally used. When using EDTA or other chelating agents, care must be taken to determine if a reaction takes place with metals to form soluble forms which escape into the effluent. If treatment is necessary, phosphate may be readily reduced to below 1 mg/l by chemical coagulation with ferris, ferrous and aluminum salts or with lime (9). The coagulation may be done before, after or even in the aeration tank of the activated-sludge process.

8.12.6 Nitrogen

Nitrogen in wastes may occur as ammonia, nitrite, nitrate or organic nitrogen. In biological-oxidation, ammonia may be converted to organic nitrogen in the bacterial bodies and to nitrites and nitrates. The organic nitrogen may be removed as sludge, but the unconverted ammonia, nitrite and nitrate are soluble and will be present in the effluent. In some cases, oxidation of the ammonia in the stream may deplete the oxygen resources in the stream, since ammonia has a very high potential oxygen demand of 423%. In addition, ammonia has a very high chlorine demand and may raise chlorine use for disinfection to high levels. This may also tend to make the effluent toxic to fish because of the chlorinated amines produced.

Ammonia removal may be accomplished in two ways. Carbonaceous BOD such as methanol may be added to aeration tank to convert the excess ammonia to organic nitrogen as bacterial bodies and may be removed as sludge. It also may be removed by raising the pH to 9 to 11 with lime or sodium hydroxide and by aerating the mixture to gasify the ammonia.

Nitrites and nitrates though usually low in textile effluents can cause problems since they may be denitrified by certain bacteria to produce nitrogen gas, which causes sludge rising in secondary settling basins. In addition, they may cause excessive algae growths in the receiving stream. They may be removed by creating favorable conditions for the denitrification process, described above to occur, but this also presents many difficulties.

The best way to solve the nitrogen problem is to limit ammonia, nitrite and nitrate use in processing. If such use is fixed to produce a BOD:N ratio of 100:5, practically all of the nitrogen will be converted to organic nitrogen and may be removed as sludge.

8.13 Sludge Treatment

Sludge treatment generally consists of all or part of digestion, dewatering and ultimate disposal. A number of alternative techniques are available as illustrated in Figure 8-29.

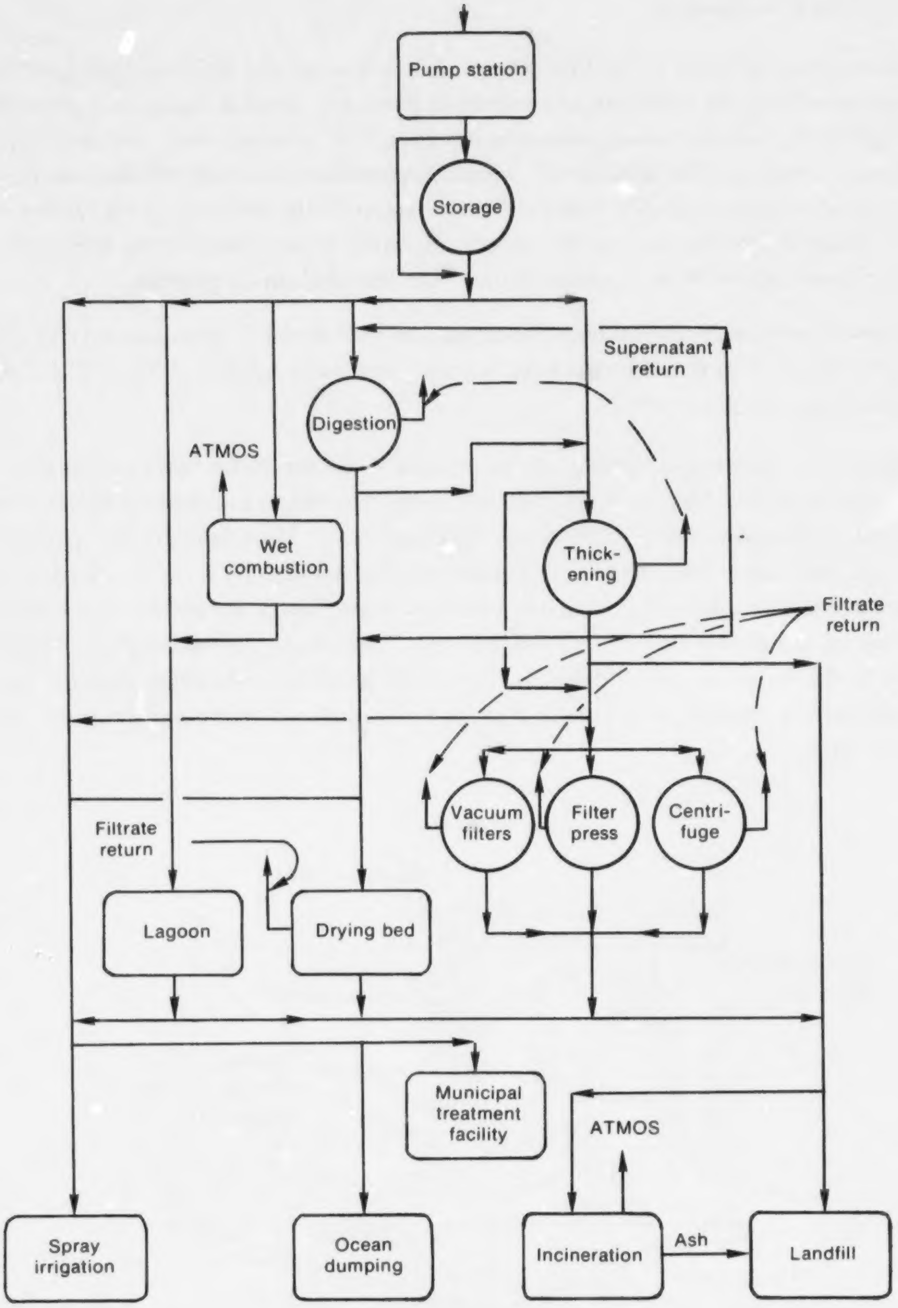

Pump station
Storage
Supernatant return
Digestion
ATMOS
Wet combustion
Thick-ening
Filtrate return
Vacuum filters
Filter press
Centri-fuge
Filtrate return
Lagoon
Drying bed
Municipal treatment facility
ATMOS
Spray irrigation
Ocean dumping
Incineration
Ash
Landfill

FIGURE 8-29

SLUDGE HANDLING, DEWATERING AND DISPOSAL

Source: National Commission on Water Quality, Textile Industry Technology and Costs of Wastewater Control, Lockwood Greene Engineers, Inc., June, 1975

8.13.1 Aerobic Digestion

The major objective of aerobic digestion is to produce a biologically stable end product suitable for disposal or subsequent treatment in a variety of processes. Aerobic digestion is generally defined as a process in which microorganisms obtain energy by endogenous or auto-oxidation of their cellular protoplasm. The biologically degradable constituents of the cellular material are slowly oxidized to carbon dioxide, water and ammonia, with the ammonia being further converted to nitrates during the process. The aerobic digestion of secondary excess activated sludge may be considered to be a continuation of the activated sludge process.

The suggested minimum detention time for excess activated sludge is approximately 15 days. If the actual temperature in the digestion basin is anticipated to be much less than 60° F., additional capacity should be provided.

In general, aerobic digesters are similar to conventional activated sludge tanks in that they are not covered or insulated. Thus they are generally more economical to construct than are covered, insulated, and heated anaerobic digesters (see Figure 8-30). Most digesters are operated on a flow-through basis where raw excess sludge enters the digester directly from the clarifier. Similar to conventional aeration tanks, if diffused aeration is employed, the aerobic digesters may be designed for spiral roll or cross roll aeration. Recently, surface mechanical aeration is finding popularity in the design of aerobic digesters. The mixing qualities and oxygen transfer capability of the surface aerators are generally superior to the diffused aeration systems per unit horsepower input.

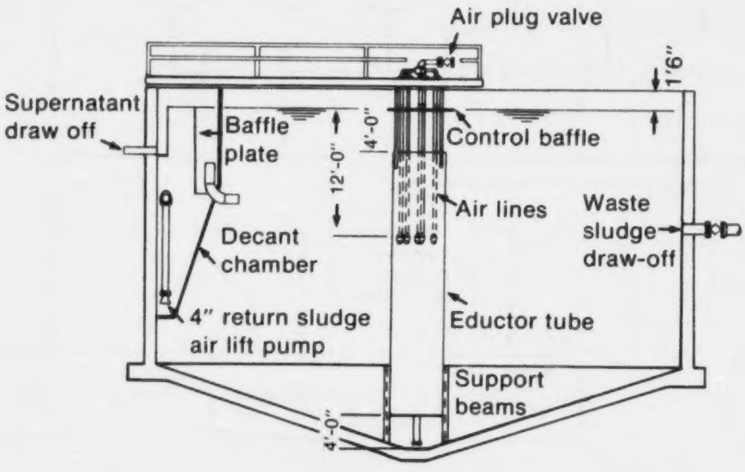


FIGURE 8-30

CIRCULAR AEROBIC DIGESTER

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

Design parameters for aerobic digesters are suggested as follows:

TABLE 8-23
DESIGN PARAMETERS FOR AEROBIC DIGESTERS

Detention Time	15 (days)
VSS Loading	0.024 to 0.14 (lb/ft^3/day)
Air Requirements:	
Diffusers	15 to 20 (cfm/1000 ft^3)
Mechanical	100 to 125 (HP/MG)
Temperature	15 (°C)
Tank Depth	15 (ft)
Volatile Solids Reduction	60 (% Eff.)

8.13.2 Sludge Thickening

Thickeners are used to decrease the hydraulic loading in sludge digestion and dewatering units and, thus, increase their efficiency in terms of the weight of solids processed per unit area or volume per unit time. The sludge may be thickened either by gravity or dissolved air flotation (see Section 8.5.4).

Gravity thickeners are continuously fed by waste sludge, and thickened sludge is continuously withdrawn from the thickener. Design is on the basis of unit area, square feed per pounds/solids per day, in which the required surface area is related to solids entering and leaving the unit.

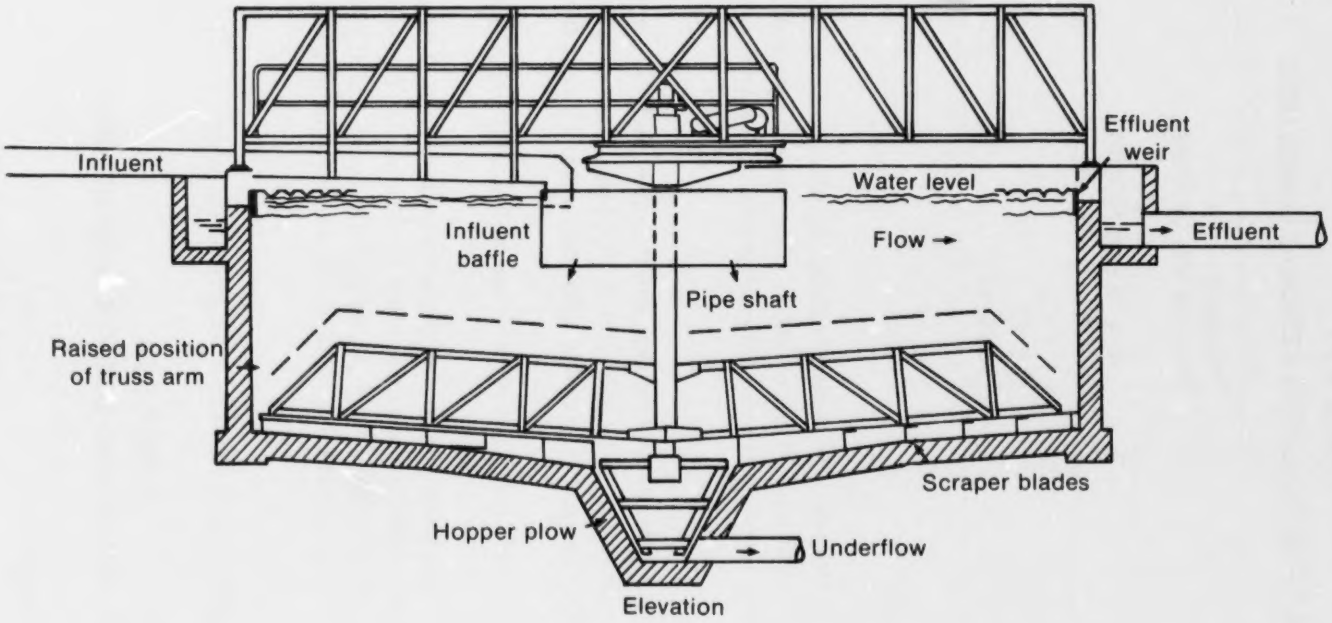
Required design data are derived from batch settling tests and analysis of the settling curve.

Gravity thickeners resemble conventional circular clarifiers with the exception of having a greater tank bottom slope and pickets on the mechanical scraping mechanism (see Figure 8-31). The pickets stir the sludge gently, release water, air and gas and push the concentrated sludge to a central collection well. In some cases, flotation thickening will produce a sludge (float) which will dewater more readily.

Following is a tabulation of typical design parameters for gravity thickening:

TABLE 8-24
GRAVITY THICKENING DESIGN PARAMETERS

Influent Solids Concentration	1.0 (%)
Solids Flux Rate	4-13 (lb SS/sq. ft-day)
Underflow SS Concentrations	2 (%)
Overflow Rate	200 (gal/day/sq. ft.)


Influent
Effluent weir
Water level
Effluent
Influent baffle
Flow →
Pipe shaft
Raised position of truss arm
Scraper blades
Hopper plow
Underflow
Elevation

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

FIGURE 8-31

GRAVITY THICKENER

8.13.3 Dewatering

In the past, sludge dewatering of textile wastes has been via the simplest and least cost options such as lagoons or drying beds. These methods appeared most attractive to the large number of mills located in the southeast where climatic conditions and land values were most suitable. With today's considerations for groundwater protection, elimination of odors and increasing land values, these methods may no longer be the best suited. Though considerably more costly, dewatering using vacuum filtration, centrifugation and filter presses are gaining in use in order to eliminate these problems. Other dewatering units include the horizontal belt/press filter, dual cell gravity filter and multi-roll press. Design experience, however, is quite limited for textile sludges, and difficulties have been encountered with each dewatering method. Chemical flocs, especially alum, are particularly difficult to dewater due to their more delicate, finely divided character.

8.13.3.1 Drying Beds

8.13.3.1a Factors Affecting Design

A most widely used dewatering method in the United States is drying of sludge on open or uncovered sandbeds. Sandbeds possess the advantage of needing little operator attention and skill. Air drying is normally restricted to well digested sludge, because raw sludge is odorous, attracts insects, and does not dry satisfactorily when applied at reasonable depths. Oil and grease discharged with raw sludge clog sandbed pores and thereby seriously retard drainage. The design and use of drying beds are affected by many parameters. They include weather conditions, sludge characteristics, land values and proximity of residences, and use of sludge conditioning aids. Climatic conditions are most important. Factors such as the amount and rate of precipitation, percentage of sunshine, air temperature, relative humidity, and wind velocity determine the effectiveness of air drying.

The nature and moisture content of the sludge discharged to drying beds influences the drying process. Sludges containing grit dry rapidly; those containing grease more slowly; aged sludge dries slower than new sludge; primary sludge dries faster than secondary sludge; and digested sludge dries faster than fresh sludge and cracks earlier. It is important that wastewater sludge be well digested for optimum drying. In well digested sludge, entrained gases tend to float the sludge solids and leave a layer of relatively clear liquid, which can readily drain through the sand. The use of dewatering polymer when pumping to a drying bed may greatly reduce drying time and increase bed efficiency.

8.13.3.1b Design Criteria for Sandbeds

Design standards vary from region to region in the United States. This variance is partly due to climatic differences. However, Table 8-25 presents typical criteria for the design of open sand drying beds.

TABLE 8-25
CRITERIA FOR THE DESIGN OF SANDBEDS

Type of Digested Sludge	Sludge Loading Dry Solids (lb/sq. ft./yr.)
Standard Trickling Filter	22.0
Activated	15.0
Chemically precipitated	22.0

Sandbeds can be enclosed by glass. Glass enclosures protect the drying sludge from rain, control odors and insects, reduce the drying periods during cold weather, and can improve the appearance of a waste treatment plant. Experience has shown that only 67 to 75% of area required for an open bed is needed for an enclosed bed. Good ventilation is important to control humidity and to optimize the evaporation rate. As expected, evaporation occurs rapidly in warm, dry weather. Adaptation of mechanical sludge removal equipment to enclosed beds is more difficult than to open drying beds.

Drying beds usually consist of 4 to 9 inches of sand which is placed over 8 to 18 inches of graded gravel or stone. The sand typically has an effective size of 0.3 to 1.2 mm and a uniformity coefficient of less than 5.0. Gravel is normally graded from 1/8 to 1.0 inch. Drying beds have underdrains that are spaced from 8 to 20 feet apart. Underdrain piping is often vitrified clay laid with open joints, has a minimum diameter of 4 inches, and has a minimum slope of about 1%. Collected filtrate is usually returned to the treatment plant (see Figure 8-32).

The Ten State Standards make the following design recommendations:

- The top 3 inches of gravel consist of 1/8 to 1/4-inch gravel
- The gravel extends at least 6 inches above the top of the underdrains
- The gravel layer should be 12 inches deep
- The sand layer should be at least 6 to 9 inches deep
- Underdrains should be no more than 20 feet apart
- Bed walls should be watertight and extend 15 to 18 inches above and at least 6 inches below the surface
- Outer walls should be curved to prevent soil from washing onto the beds
- At least 2 beds should be provided
- Pairs of concrete truck tracks at 20-foot centers should be provided for all beds
- The influent pipe should terminate at least 12 inches above the surface with concrete splash plates provided at discharge points.

Mechanical lifting of sludge has been practiced for many years at some large treatment plants, but now it is receiving more attention as labor costs continue to rise. Mechanical devices can remove sludges of 20 to 30% solids while cakes of 30 to 40% are generally required for hand removal.

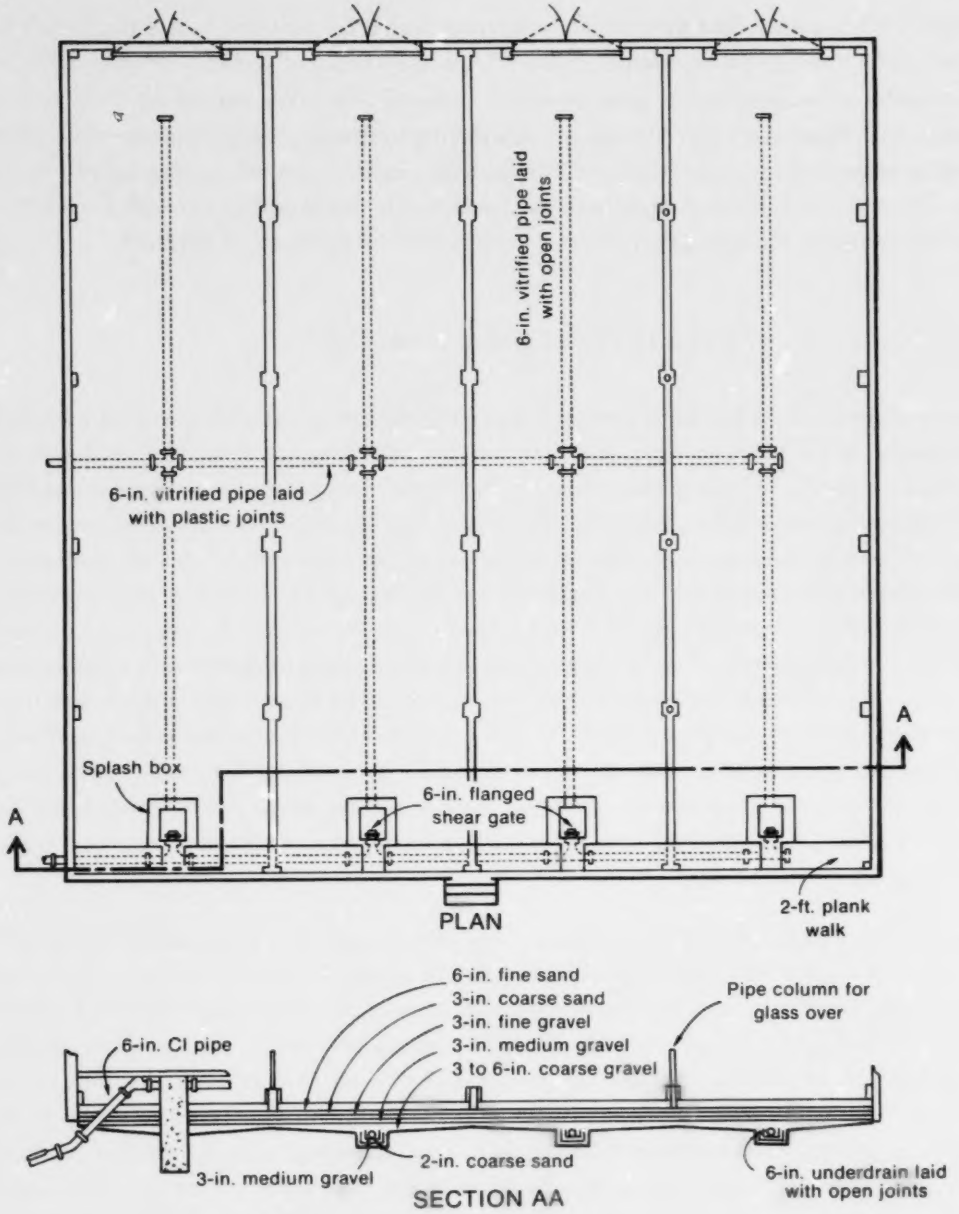

6-in. vitrified pipe laid with open joints
6-in. vitrified pipe laid with plastic joints
A
A
Splash box
6-in. flanged shear gate
2-ft. plank walk
PLAN
6-in. fine sand
3-in. coarse sand
3-in. fine gravel
3-in. medium gravel
3 to 6-in. coarse gravel
Pipe column for glass over
6-in. CI pipe
3-in. medium gravel
2-in. coarse sand
6-in. underdrain laid with open joints
SECTION AA

FIGURE 8-32

SLUDGE DRYING BED

Source: Metcalf & Eddy, Wastewater Engineering: Collection, Treatment, Disposal

8.13.3.1c Results of Sandbed Drying

Typical performance data show rapid dewatering during the first one to two days while water removal by drainage predominates. This is followed by two to five weeks of slow dewatering principally by evaporation. In good weather, a cake of 45% solids may be achieved in six weeks with a well digested sludge. As with any dewatering technique, the performance of a sandbed may be improved by proper chemical conditioning, and the dewatering time may be reduced by 50% or more. Liftable sludges have been achieved in less than one day with proper chemical conditioning. Solids contents at 85 to 90% have been achieved on sandbeds.

8.13.3.1d Other Types of Drying Beds

In recent years, there has been increased interest in the use of paved drying beds with limited drainage systems for dewatering wastewater sludges. The original reasons for proposing paved bed design were to permit the use of mechanical equipment for cleaning the beds and thereby to reduce the cost of labor and sand replacement. Modification of drying beds to provide only limited drainage facilities does not necessarily impair bed performance. In fact, the use of paved drying beds with limited drainage resulted in shorter drying time as well as more economical operation when compared with conventional sandbeds. The shorter time occurred because the use of mechanical equipment for cleaning permits the removal of sludge with a higher moisture content than in the case of hand cleaning. The use of paved beds of center drain design for dewatering aerobically digested activated sludge is not as desirable as conventional sandbeds. Lateral drainage of activated sludge on paved bed is very poor and does not contribute significantly to the dewatering process. The supernatant overlying the sludge cake may drain but the reduced drainage area of the paved bed compared to the sandbed greatly hampers the rate of drainage for aerobic sludges.

Wedge wire drying beds have been used successfully in England, a cross-sectional view of one is shown in Figure 8-33. This approach prevents the rising of water by capillary action through the media, and the construction lends itself well to mechanical cleaning. The first United States installations have been made at Rollinsford, New Hampshire, and in Florida. The procedure used for dewatering sludge begins with the placement of water or effluent to a depth of up to 1 inch over the wedge wire. This water serves as a cushion permitting the added sludge to float without causing upward or downward pressure across the wedge wire surface and prevents compression or other disturbance of colloidal particles. The water is then run off by opening the control valve and controlling the rate so as to prevent a turbid effluent from the bed. After the free water has been drained, the bed is allowed to dry by drainage and evaporation until the sludge can be removed. It is possible, in small plants, to place the entire dewatering bed in a tiltable unit from which sludge may be removed merely by tilting the entire unit mechanically.

The Rollingford, New Hampshire, plant reports that it dewaters excess activated sludge conditioned with polymers from two percent solids to a liftable condition in four hours.

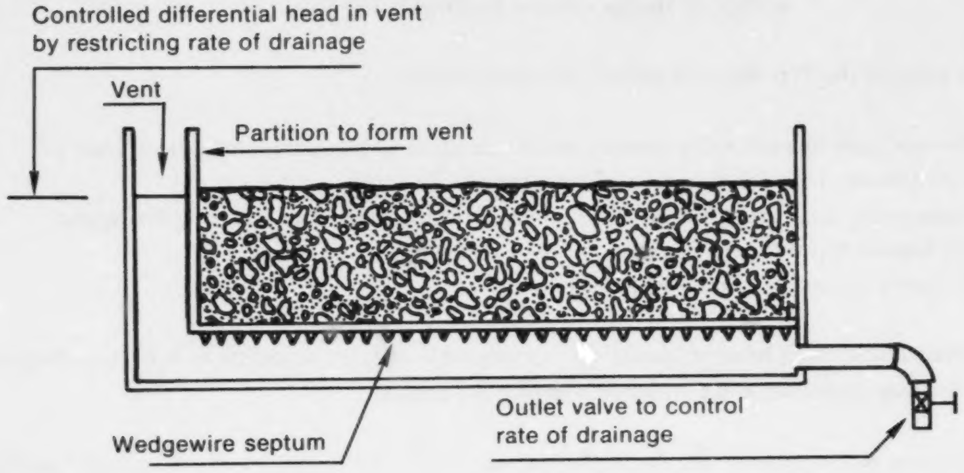

Controlled differential head in vent by restricting rate of drainage
Vent
Partition to form vent
Wedgewire septum
Outlet valve to control rate of drainage

FIGURE 8-33

WEDGEWIRE DRYING BED (Cross Section)

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

8.13.3.2 Drying Lagoons

8.13.3.2a Factors Affecting Design

Lagoon drying is a low cost, simple system for sludge dewatering that has been commonly used in the United States. Drying lagoons are similar to sandbeds in that the sludge is periodically removed and the lagoon is refilled. Lagoons have seldom been used where the sludge is never removed, because such systems are limited in application to areas where large quantities of cheap land are available. Sludge is stabilized to reduce odor problems prior to dewatering in a drying lagoon. Odor problems with lagoons can be greater than with sandbeds, because sludge in a lagoon retains water for a longer period than does sludge on a conventional sand drying bed.

Other factors affecting design include consideration of groundwater protection and access control. Major design factors include climate, subsoil permeability, lagoon depth, loading rates, and sludge characteristics. The design should provide for uniform distribution of the sludge and for decanting of supernatant to speed the drying process.

8.13.3.2b Design Criteria for Drying Lagoons

Criteria cited in the Ten States Standards are given below:

- The soil must be reasonably porous, and the bottom of the lagoon must be at least 18 inches above the maximum groundwater table.
- Surrounding areas must be graded to prevent surface water from entering the lagoon.
- The lagoon depth should not be more than 24 inches.
- At least two lagoons should be provided.

Underdrains have often been proposed where permeable soils are unavailable; however, evaporation is the main mechanism for water removal from a lagoon.

Solids loading rates suggested for drying lagoons are 2.2 to 2.4 lb./yr./cu. ft. of lagoon capacity. A dike height of about 2 feet with the depth of sludge after decanting of 15 inches has been used. Sludge depths of 2.5 to 4 feet may be used in warmer climates where longer drying periods are possible. Dikes should be of a shape and size to permit maintenance, mowing and entrance of trucks and front-end loaders for sludge removal.

8.13.3.2c Results of Lagoon Drying

Sludge will generally not dewater in any reasonable period of time to the point that it can be lifted by a fork except in an extremely hot, arid climate. If sludge is placed in depths of 15 inches or less, it may be removed with a front-end loader in 3 to 5 months. When sludge is to be used for soil conditioning, it may be desirable to stockpile it for added drying before use. One proposed approach utilizes a 3-year cycle in which the lagoon is loaded for 1 year, dries for 18 months, is cleaned, and is allowed to rest for 6 months. Definitive data on lagoon drying are scarce. Sludge may be dewatered from 5% solids to 40 to 45% solids in 2 to 3 years using sludge depths of 2 to 4 feet.

8.13.3.3 Vacuum Filtration

The function of the vacuum filtration unit is to dewater sludge under applied vacuum by means of a porous medium which retains the solid but allows the liquid to pass. Vacuum filtration is a continuous process generally accomplished on a cylindrical drum which passes through the slurry tank and retains solids on its surface due to an internal vacuum. Drum media may be of cloth, steel mesh or tightly wound coil springs (see Figure 8-34).

Textile sludges tend to blind the filter medium rapidly. It is possible to reduce this tendency by using chemical coagulants which reduce specific resistance and increase filtration rate. Common coagulants used for this purpose include ferric chloride, lime and organic polyelectrolytes.

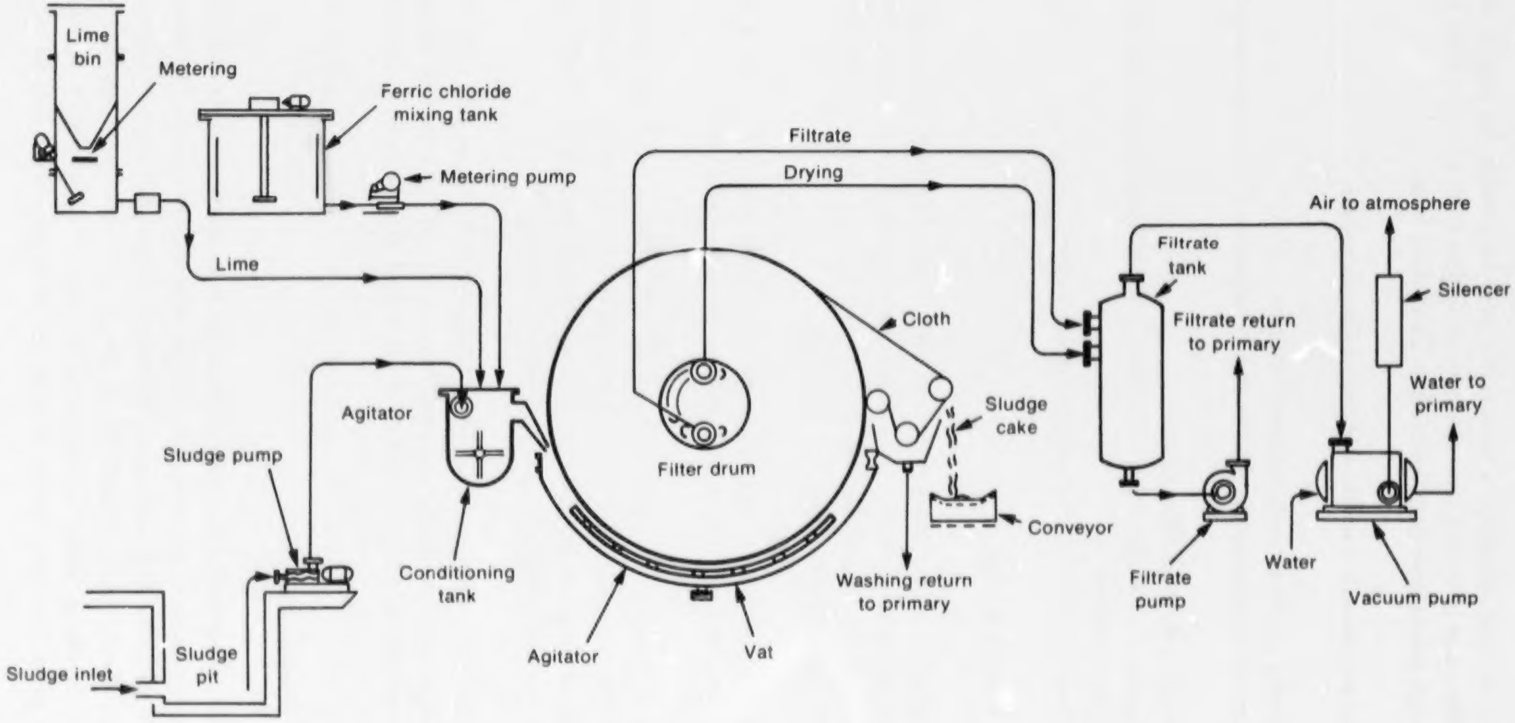

Lime bin
Metering
Ferric chloride mixing tank
Metering pump
Lime
Agitator
Sludge pump
Conditioning tank
Sludge inlet
Sludge pit
Filtrate
Drying
Filter drum
Agitator
Vat
Cloth
Sludge cake
Conveyor
Washing return to primary
Filtrate tank
Filtrate return to primary
Filtrate pump
Air to atmosphere
Silencer
Water to primary
Water
Vacuum pump

FIGURE 8-34

ROTARY VACUUM FILTER SYSTEM

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

A vacuum filter loading of approximately 3 lb/sq.ft./hr. may be suitable for textile sludges; however, due to the differences in drying characteristics of sludges from plant to plant it is essential to develop design parameters from leaf tests or pilot-plant tests.

The New England Standards provide a number of design considerations:

- Chemical conditioning should precede vacuum filtration
- Filter operation usually does not exceed 30 hrs/wk to allow time for conditioning and cleaning
- Provide a variable speed drive on filter drum
- Provide vacuum pumps with a capacity of 1.5 cfm/sq. ft. for fabric coated type and 3 cfm/sq. ft. for metal-covered
- Provide filtrate pump and return filtrate to raw waste stream

8.13.3.4 Centrifugation

Centrifuges have been widely used by industry for separating liquids of different densities or removing solids. The unit operates basically by feeding a sludge through a stationary feed pipe and by settling solids out against the bowl wall by contrifugal force. A screw continuously conveys the solids to the end of the machine for discharge.

There are a number of different types of centrifuges on the market today. The type most often used for dewatering sludge is the horizontal solid bowl as shown in Figure 8-35.

As in the case of vacuum filtration, chemical conditioning will improve the dewatering process. One textile finishing mill dewatering a combination biological/chemical sludge uses a cationic polymer at 10 to 20 lbs/ton of dry solids for conditioning. A sludge cake with a solids concentration of 12 to 15% is produced with a 95 to 99% solids recovery (10).

Design considerations given by the New England Standards are for the most part very similar to those for vacuum filtration. In addition, special considerations should be made for foundations and soundproofing because of the vibration and noise associated with the operation of the centrifuge.

8.13.3.5 Pressure Filtration

The plate and frame filter press is a batch device, which has been used in industry and in European wastewater plants for many years to process sludges difficult to dewater. The press consists of vertical plates which are held rigidly in a frame and which are pressed together between a fixed and moving end as illustrated in Figure 8-36. On the face of each individual plate is mounted a filter cloth. The sludge is fed into the press and passes through feed holes in the trays along the length of the press. The water passes through the cloth while the solids are retained

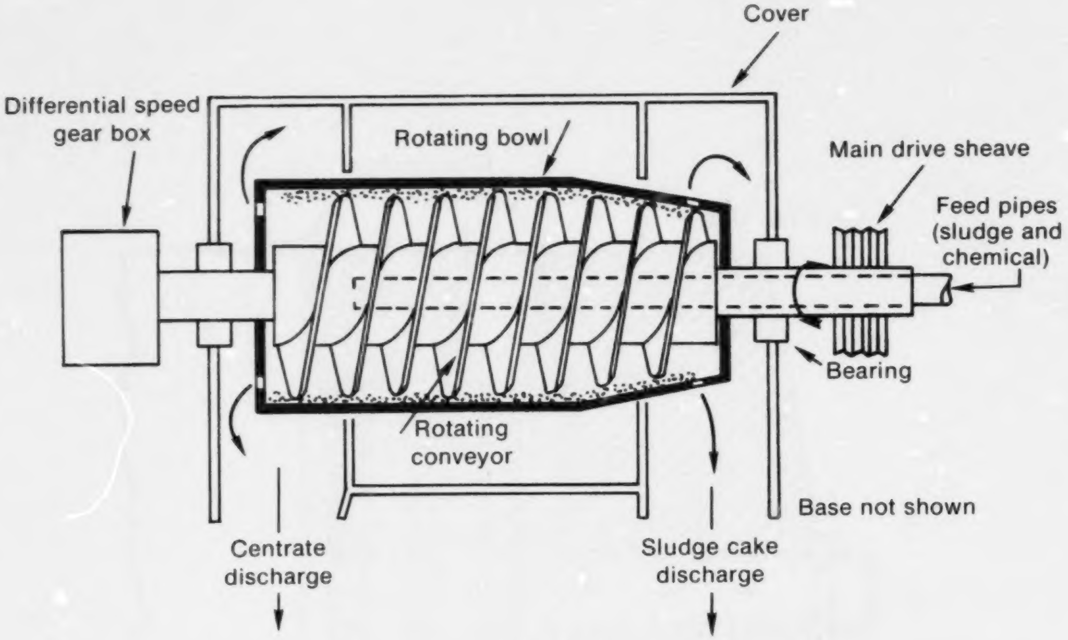

Cover
Differential speed gear box
Rotating bowl
Main drive sheave
Feed pipes (sludge and chemical)
Bearing
Rotating conveyor
Base not shown
Centrate discharge
Sludge cake discharge

FIGURE 8-35

CONTINUOUS COUNTERCURRENT SOLID BOWL CENTRIFUGE

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

forming a cake on the surface of the cloth. Sludge feeding is stopped when the cavities or chambers between the trays are completely filled. Drainage ports are provided at the bottom of each press chamber. The filtrate is collected in these, taken to the end of the press, and discharged to a common drain. At the commencement of a processing cycle, the drainage from a large press can be in the order of 2,000 to 3,000 gallons per hour. This rate falls rapidly to about 500 gallons per hour as the cake begins formation and to virtually nothing when the cake completely fills the chamber. The dewatering step is completed when the filtrate is near zero. At this point the pump feeding sludge to the press is stopped and any back pressure in the piping is released through a bypass valve. The electrical closing gear is then operated to open the press. The individual plates are next moved in turn over the gap between the plates and the moving end. This allows the filter cakes to fall out. The plate moving step can be either manual or automatic. When all the plates have been moved and the cakes released, the complete pack of plates is then pushed back by the moving end and is closed by the electrical closing gear. The valve to the press is then opened, the sludge feed pump is started, and the next dewatering cycle is begun.

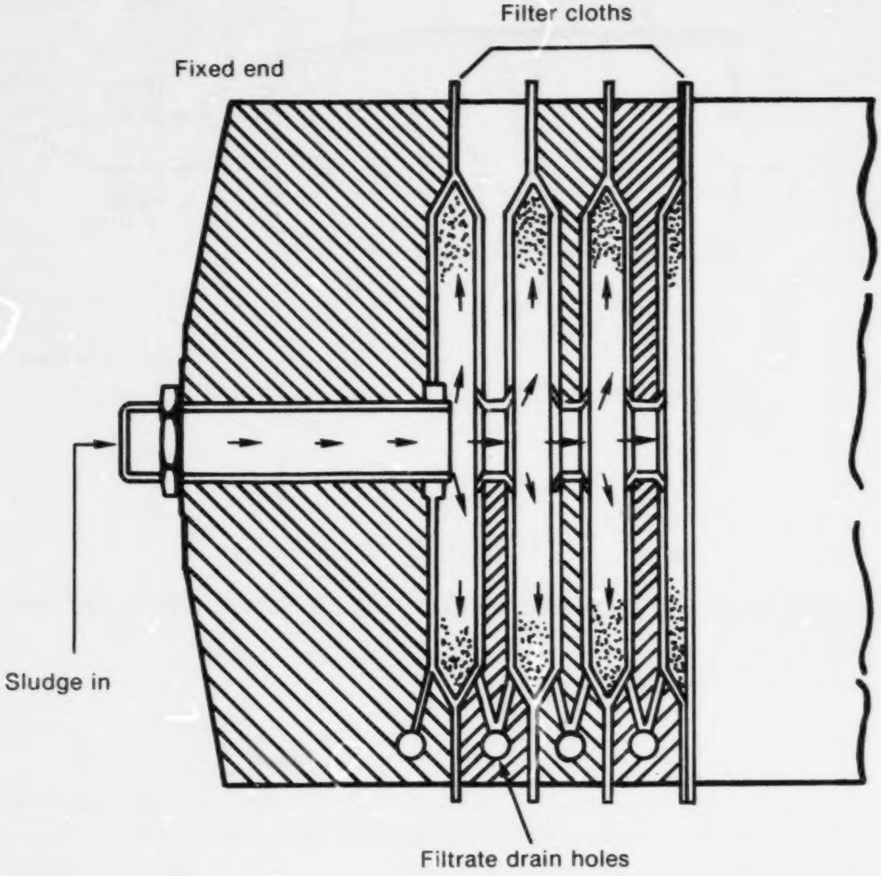

Filter cloths
Fixed end
Sludge in
Filtrate drain holes

FIGURE 8-36

CUTAWAY VIEW OF FILTER PRESS

Source: Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal

One manufacturer has pilot tested pressure filtration of activated sludge from treatment of dyehouse wastewater. Depending upon sludge thickening methods used (alum or polymers) and the concentration of sludge entering (1 to 3%) the filter system, results were as follows (21):

Sludge Conditioning Chemical	Hydrated Lime
Filtration Cycle Time	75 to 120 min.
Filter Pressure	225 psig
Filter Cake Solids	33 to 39% dry
Filter Cake Density	70 to 75 lb/cu. ft.

8.14 Sludge Disposal

8.14.1 Spray Irrigation

Design criteria for sludge disposal by spray irrigation is not well suited to standardized parameters as the acceptability and success are related to many variables. Of special consideration in the design of a land application system are the following:

- Sludge Characteristics (heavy metals, etc.)
- Climate
- Geology
- Soil Type
- Plant Cover
- Topography
- Spray Method Used
- Potential Production of Viable Aerosols

A large finishing mill has successfully spray irrigated aerobically digested sludge for more than 8 years (22). Figure 8-37 illustrates a typical spray irrigation system.

The following general requirements were established by the State of South Carolina for the physical characteristics of a spray site. Additional requirements are found in Addendum No. 2 (April, 1971) of the Ten States Standards:

- Water table depth must be greater than five feet
- Spray rate equal to or less than 2 in/wk or 1/4 in/day depending upon soil type, slopes, etc.
- Soil types – silty or sandy loams (GM-d, SM-d, ML, OL, MH and PT classification).
- Spray schedule – spray 8 hours and rest 160 hours or spray 4 hours and rest 80 hours
- Holding pond – 4 to 7 day holding pond
- Two-foot berm around entire spray area
- Percolation rate – 4 to 15 min/in

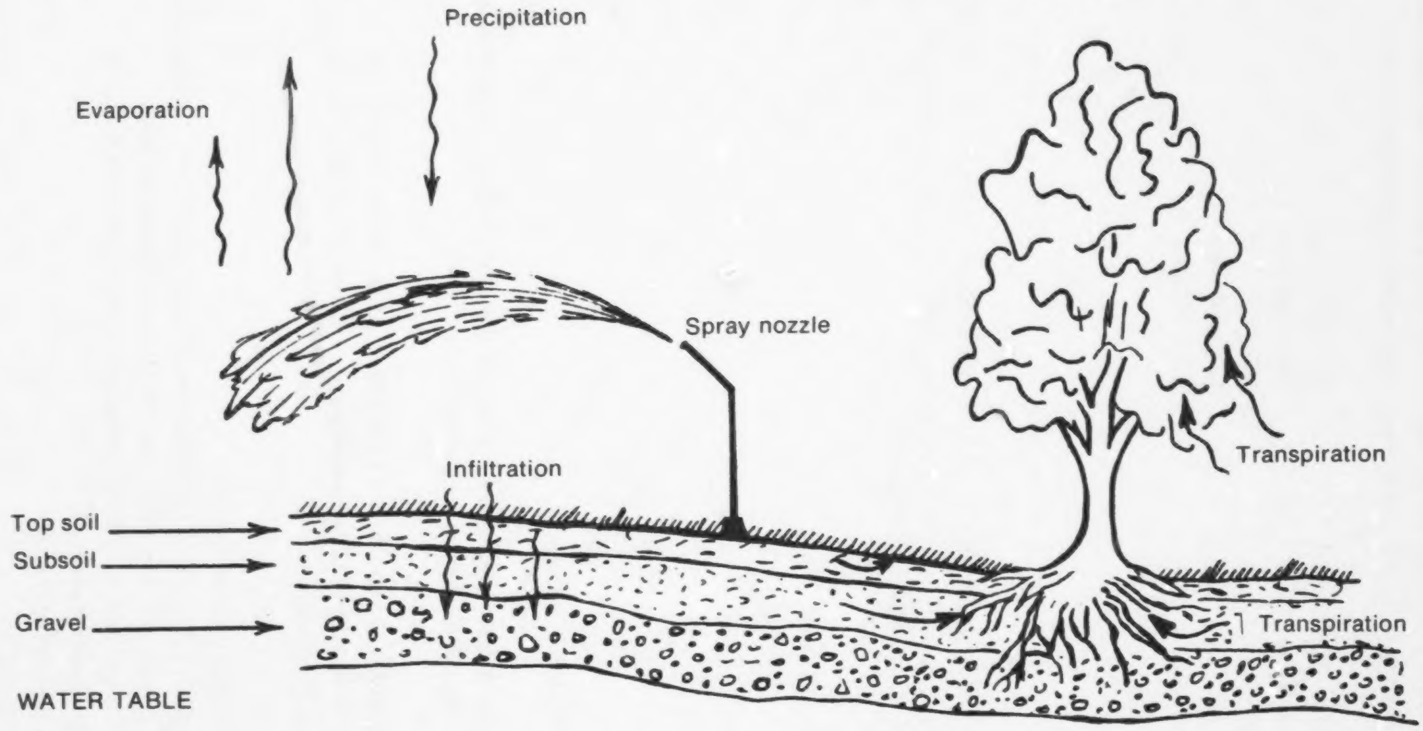

Precipitation
Evaporation
Spray nozzle
Transpiration
Infiltration
Top soil
Subsoil
Gravel
Transpiration
WATER TABLE

FIGURE 8-37

SPRAY IRRIGATION

Source: Environmental Engineer's Handbook

- Buffer zone – 100 feet beyond spray influence
- Slopes – less than 10%
- Maintain natural vegetation and natural topsoil, as much as possible, adding mulch to bare or disturbed areas
- Groundwater monitoring well to test subsurface aquifier located in direction of groundwater flow
- Fencing and appropriate signs around spray site and buffer zone

8.14.2 Landfill

The disposal of industrial and potentially hazardous wastes is generally regulated by State environmental agencies. Regulations are established for the following types of disposal sites:

- Sanitary
- Milled or Shredded Refuse
- Industrial

Though there is a potential for disposal of industrial wastes at sanitary and shredded refuse sites, each request is considered on a case-by-case basis. Solid waste generated at industrial sources is generally divided into five categories:

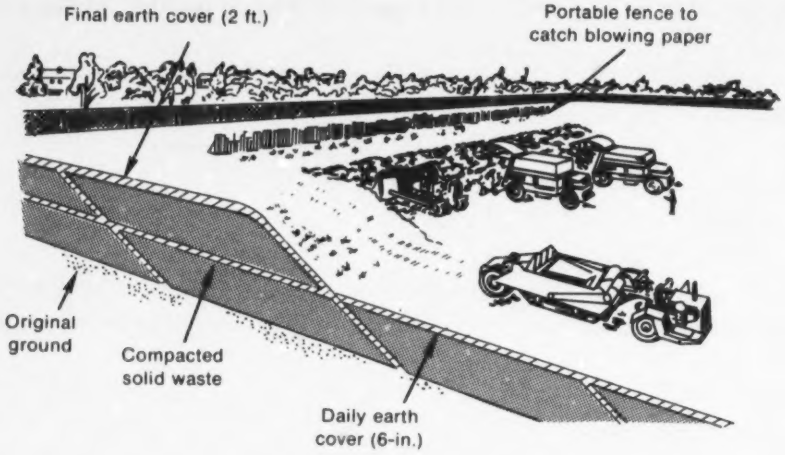
- Putrescible
- Non-burnable
- Cellulosic
- Inert
- Hazardous

The State of South Carolina includes as hazardous wastes: solvents, solvent residues, oils and grease, heavy metals, dyes, chemical precipitates, sludges, and slurries.

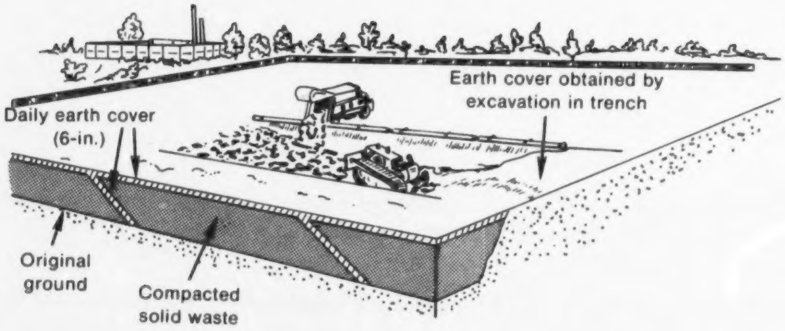
Landfill sites may be privately owned, owned by a municipality, or constructed by the textile mill. State permits are generally required for disposal on company owned land. If wastes are not found acceptable for disposal into an existing landfill it will be necessary to consider disposal to an area used exclusively for the particular waste, chemical fixation and burial, encapsulation and burial, or possible incineration. Figure 8-38 illustrates both the area method and trench method of landfilling.

The important considerations in locating and designing a landfill are as follows:

- The site should be easily accessible and safeguarded against uncontrolled gas movement
- The site should provide for adequate protection of groundwater
- An adequate quantity of earth cover should be available at the site


Final earth cover (2 ft.)
Portable fence to catch blowing paper
Original ground
Compacted solid waste
Daily earth cover (6-in.)

AREA METHOD


Earth cover obtained by excavation in trench
Daily earth cover (6-in.)
Original ground
Compacted solid waste

TRENCH METHOD

FIGURE 8-38

SANITARY LANDFILL

Source: Environmental Engineer's Handbook

- Wastes are to be spread in uniform layers not to exceed 2 feet thick
- Compacted wastes should have a minimum cover of 2 feet of compacted earth
- Monitoring of the system should include groundwater observation wells, surface water, and soils.

8.14.3 Incineration

Sludge disposal via on-site incineration is generally not practiced at textile facilities due to high costs and potential air pollution problems. Textile wastes are generally low in Btu value. For mills with limited land available for sludge drying beds or lagoons it may be possible to reduce sludge volume by thickening and dewatering and to haul sludge cake to a central incineration facility. Two types of incinerators in common use for sludge are the multiple hearth and fluidized bed. The multiple-hearth incinerator consists of four or more refractory lined trays and is operated at about 1350° F. A fluidized bed consists of sand suspended in air and heated to a temperature of 1400 to 1500° F.

8.15 Disinfection

Disinfection for the reduction of fecal coliforms is generally not limited to point source discharges until the deadline for BAT. (Dry processing mills are limited to 400/100 ml for 1977). Water quality limited discharges, however, may require disinfection by 1977.

Fecal coliform may be present in most textile wastes from domestic facilities. Experience has shown that due to the chemical concentration of textile wastewater, some effluents exhibit a very low or non-existent fecal coliform count. Segregation of sanitary streams has the advantage of reducing required disinfecting facilities to handle less than 5% of the total plant flow. Disinfection is most often accomplished with the use of chlorine; however, ozone has recently gained partial acceptance.

8.15.1 Chlorination

When chlorine is added to water, two reactions, hydrolysis and ionization, take place as shown in the following:

Hydrolysis

$$Cl_2 + H_2O \longrightarrow HOCl \quad + \quad H+ \quad + \quad Cl$$

(Chlorine Gas) (Hypochlorous + Acid) (Hydrogen + ion) + (Chloride ion)

Ionization

$$HOCl \longrightarrow OCl^- \quad + \quad H^+$$

(Hypochlorite ion)

Ionization is dependent upon the pH and temperature of the wastewater. The quality of $HOCl$ and OCl^- that is present in water is called the free available chlorine. Free chlorine can also be added to water in the form of hypochlorite salts such as calcium hypochlorite. The free chlorine in solution will react with ammonia or organic amines to form chloramines which also serve as disinfectants, although they are slower reacting.

The quantity of chlorine required for disinfection will depend upon chlorine demand; that is, the amount of chlorine which will combine with various chemicals before it begins to appear as a free chlorine residual. The actual dosage required will vary depending upon the characteristics of the wastewater (organics present, pH, etc.) and therefore is best determined by laboratory studies.

Chlorine is fed into wastewater either directly as a gas or is mixed with a small flow of water to produce a precisely controlled, concentrated solution which is then injected into the waste stream (see Figure 8-39). When hypochlorite is used, it is mixed in a drum to form a concentrated solution and is fed by a diaphragm or metering pump. The design goal of the chlorine mixing process is to provide rapid, intimate mixing of the chlorine solution stream with the wastewater stream in the shortest possible period. Mixing methods include turbulent flow in a pipe, mechanical in-line mixing, or the use of a hydraulic pump.

Chlorine is contacted with the wastewater for a period of time (usually 15 to 30 minutes) in a contact chamber or equivalent volume effluent pipe. Currently there are no commonly accepted design criteria for contact tanks. They may be circular, rectangular with transverse baffling, or rectangular with longitudinal baffling. Of importance is the avoidance of short circuiting and solids deposition.

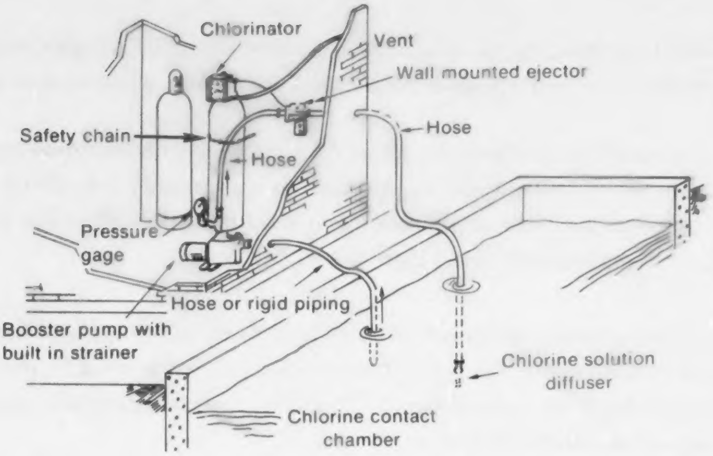

Chlorinator
Vent
Wall mounted ejector
Safety chain
Hose
Hose
Pressure gage
Hose or rigid piping
Booster pump with built in strainer
Chlorine solution diffuser
Chlorine contact chamber

FIGURE 8-39

CHLORINATION

Source: Capital Controls Company

Control of the chlorination system will depend upon wastewater flow. If the flow rate is constant, a manual feed system may be adequate. If the flow is variable, the system may be controlled by flow rate alone or in combination with a residual chlorine analyzer.

The following tabulation lists a range of design parameters used in chlorination:

TABLE 8-26
CHLORINATION DESIGN PARAMETERS

Chlorine Dosage	5 to 15 mg/l
Contact Time	15 to 30 min. (@ max. hourly flow)
Effluent Residual	0.2 to 1 mg/l
Chlorine Forms:	Liquid (gas at room temp.) Powder (Calcium Hypochlorite) Solution (Sodium Hypochlorite)

8.15.2 Ozonation

Ozone is a powerful oxidizing agent; in fact, its oxidation potential is higher than all commonly used oxidizing agents. It effectively destroys bacteria and viruses when used as a disinfectant.

Ozone may be generated on site from dry air or from oxygen. There are two types of generators used, the tube type and the plate type. The generators convert only 1 to 4% of the feed oxygen gas into ozone. Because of its low solubility, ozone is fed into the wastewater by diffusing or injecting it into a mixing chamber (see Figure 8-40).

The advantages of using ozone for disinfection include its rapid action; no danger of overtreatment; unaffected by temperature and pH; reduces color (see Section 8.11), phenol and BOD; and its oxidation products are not poisonous. The following tabulation lists some considerations in the design of an ozonation system:

TABLE 8-27
OZONATION DESIGN PARAMETERS

Ozone Dosage	5 to 25 mg/l
Contact Time	1 to 5 minutes
Ozone Concentration in Generated Air or Oxygen	1 to 2% by weight
Power Consumption:	
From Air	10 to 13 kwh/lb. ozone
From Oxygen	5 to 6 kwh/lb. ozone

8.16 Emerging Technology

8.16.1 Pure Oxygen Activated Sludge

Pure oxygen activated sludge is a relatively new modification of the conventional activated sludge process. Recent advances in oxygen production technology have improved the economics of this system. There are two proprietary systems currently being marketed in the United States. Generally, the oxygen gas is generated on site using either the cryogenic process or the absorption process.

Atmospheric oxygen (21% by volume) has a relatively low solubility in water (9 mg/l at 20° C.). In the pure oxygen system (90 to 100% volume) the solubility is increased to almost 45 mg/l. This allows a more rapid reduction of BOD and may result in less horsepower consumed per pound of oxygen dissolved.

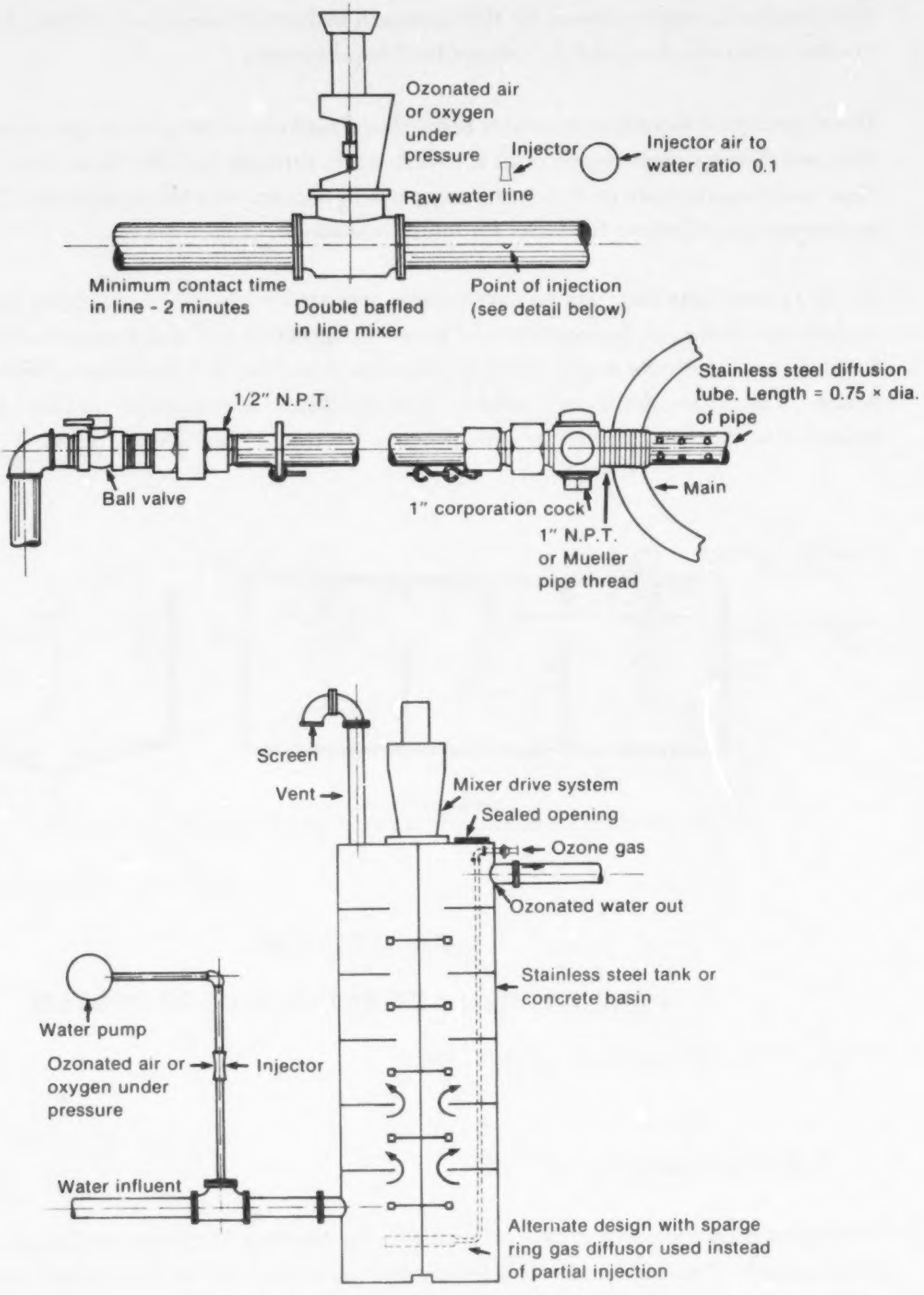

Ozonated air or oxygen under pressure
Injector
Injector air to water ratio 0.1
Raw water line
Minimum contact time in line - 2 minutes
Double baffled in line mixer
Point of injection (see detail below)
Stainless steel diffusion tube. Length = 0.75 × dia. of pipe
1/2" N.P.T.
Ball valve
Main
1" corporation cock
1" N.P.T. or Mueller pipe thread
Screen
Vent
Mixer drive system
Sealed opening
Ozone gas
Ozonated water out
Stainless steel tank or concrete basin
Water pump
Ozonated air or oxygen under pressure
Injector
Water influent
Alternate design with sparge ring gas diffusor used instead of partial injection

FIGURE 8-40

OZONE INJECTION METHODS

Source: Water and Wastes Engineering, Nov., 1974, Ozone for Water! What's the Story?, Harris, W. C.

Additional advantages claimed for this approach include: 1) improved settling characteristics; 2) elimination of odors; and 3) reduced land requirements.

The typical pure oxygen system uses three closed tanks in series with oxygen entering the first tank and flowing concurrently with the wastewater through the third tank which is vented. Slow speed aerators are used to bring oxygen into contact with the wastewater. The aerator motors are placed above the tanks for safety reasons (see Figure 8-41).

At the present time there are no pure oxygen activated sludge systems treating textile waste exclusively. There are, however, several plants in operation and under construction which effectively treat domestic waste with contributions from textile mills of up to 80% of the total volume. There have also been a number of treatability tests performed on 100% textile wastes, including waste containing PVA, with effective treatment results being reported in most cases.

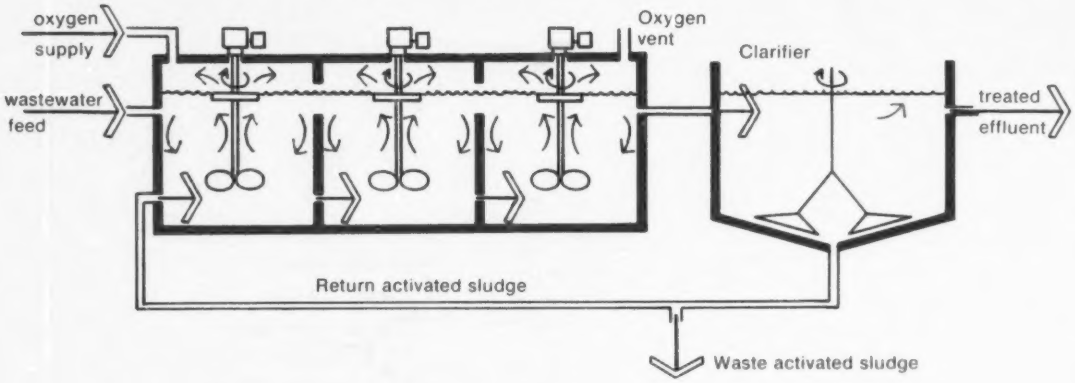


FIGURE 8-41

PURE OXYGEN ACTIVATED SLUDGE SYSTEM

Source: Lockwood Greene Engineers, Inc.

8.16.2 Ultrafiltration

Ultrafiltration is a separation process involving the filtering of an aqueous solution by a membrane capable of removing macromolecules and suspended solids. Thus, salts, solvents and low molecular weight organic solutes pass through the filter membrane into the permeate.

A 25 micron cartridge filter is used to pre-filter the wastewater before entering the ultrafiltration unit. Pressure required for operating the ultrafiltration unit is approximately 100 to 200 psi. Ultrafiltration membranes are cleaned periodically depending upon waste characteristics. Replacement of filter membrane depends upon membrane tolerance to wastewaters.

The ultrafiltration technique has been demonstrated in treating wastewaters from metal finishing operations and food processing plants.

A pilot testing program recently completed at a knit fabric finishing mill indicates substantial removals of oils (knitting oils) and dyes with the potential of recovery and reuse of greater than 90% of the treated dyehouse wastewaters. Maintaining flow rates through the system has been a problem, and long-term testing will be necessary to determine applicability to textile wastewaters containing knitting oils (23).

8.16.3 Hyperfiltration (RO)

Reverse osmosis (RO) is a process whereby dissolved salts are separated from solution by filtering through a semi-permeable membrane at a pressure greater than the naturally occurring osmotic pressure. Colloidal and organic matter that foul the membrane surfaces can cause high losses in the quantity of water than can be produced. Salts with low solubility will precipitate on the membrane and will reduce the quality of product water. Treatment of the wastewater prior to application of RO, such as activated carbon adsorption or chemical precipitation followed by filtration, should be added to prevent these losses. Concentrated liquors from the membrane exchange can be incinerated, in which case scrubbers may be required to protect air quality.

Two basic membrane materials are in use today; cellulose acetate and aromatic polyamide. There are three basic membrane configurations; the tabular, the spirally wound, and the hollow fiber. Of these, the hollow fiber has the most compact equipment.

Though unaware of the use of RO at any textile treatment facility, this process looks promising. The RO process results in excellent color removal and substantial removal of residual BOD and COD (using carbon adsorption, chemical coagulation, or filtration as a pretreatment). A form of RO known as hyperfiltration has been recently studied at a pilot plant level using a dyeing and finishing plant wastewater. Results indicate recovery of 75 to 90% of the water with successful reuse in production dyeing (16).

Another potential application of reverse osmosis is recovery of sizing materials. CMC and PVA will both be retained at great efficiency, allowing these sizing materials to be concentrated for reuse.

8.16.4 Ion Exchange

Ion exchange is a process in which ions of given species are displaced from an insoluble exchange material by ions of a different species in solution. Upon exhaustion of the exchange medium (resin), the system can be regenerated by flushing with a concentrated solution of the original ion. The exchanged ions in the waste stream are usually concentrated and disposed of by other means such as evaporation.

This method might not be practical for textile waste since organic material can cause ion exchange material to foul. Treatment of secondary effluents for suspended solids and organic removal is necessary.

A British textile finishing plant uses ion exchange and adsorption to treat dyehouse wastewaters and reclaim process water. Chemical coagulation and clarification are used as a pretreatment (24). The system works as follows:

1. Flocculating chemical and coagulants are vigorously mixed with effluent in the rapid mixing tank.

2. Low-speed mixing follows to facilitate formation of floc in flocculating basin.

3. Floc settles in settling basin, clarified water is withdrawn at the top, and sludge is collected in separate tank.

4. Clarification tank.

5. Ion exchange and adsorption tank which consists of three sections: The first contains a special patented resin. The resin was developed to remove high molecular weight compounds through ion exchange and adsorption. The second and third sections contain special cationic and macroporous anionic resins for the exchange of metals and salts, and for the adsorption of low molecular weight compounds. After leaving the ion exchange component, the water is piped to the reservoir. It is reusable for the various processes.

6. Caustic soda is employed to regenerate the ion exchanger.

In textile wastewater treatment, one advantage of using this process is that ion exchange is applicable to highly alkaline waste streams. If the effluent is sodium hydroxide, the anion exchanger alone may be used.

It appears that projected costs of ion exchanges for textile waste clean up are sufficiently low to justify a study to determine long-term applicability.

8.16.5 Electrodialysis

Electrodialysis is a type of ion separation using applied electrical potentials rather than ion "exchange".

Problems associated with the electrodialysis process for wastewater renovation include chemical precipitation of salts with low solubility on the membrane surface and clogging of the membrane by the residual colloidal organic matter. To reduce membrane fouling, activated carbon, chemical precipitation, and mixed media filtration may be necessary for pretreatment.

Electrodialysis has not been used for treatment of textile wastewater although some efforts have been made to investigate its use in dye removal. Because of their large molecular size, dye materials do not traverse the membranes readily. There may be some possibility of using electrodialysis to remove dissolved salts from dye solutions but this has not yet been demonstrated.

8.16.6 Evaporation (Distillation)

Evaporation is the oldest demineralization process. It separates wastes from water through a liquid vapor conversion. The water is converted to steam, leaving non-volatile waste behind. When it is condensed back to liquid form, it may be very pure.

To carry out evaporation at reasonable cost, it is necessary to devise special equipment that will allow for multiple reuse of the heat needed to vaporize the water. Three general types of equipment employed are multi-stage flash evaporation, vertical tube evaporation, and thermal recompression evaporation.

Textile wastewater has a moderately high concentration of organic chemicals in comparison with the concentrations in brackish or saline waters; therefore, it may be necessary to remove organic matter first by activated carbon before going to evaporation. Organic chemicals may have appreciable vapor pressure at the temperature of evaporation. Vapor-liquid equilibrium relationships will determine whether these organic pollutants can be removed successfully by evaporation.

Consequently, the application of evaporation to wastewater demands a thorough consideration and knowledge of the physical chemistry of these wastewaters, especially vapor-liquid equilibrium, and the subsequent determination of the quality of the condensate acceptable for reuse. If the wastewater contains very low concentrations of organics and high concentrations of dissolved inorganic salts, the applicability of evaporation is more readily predicted, being essentially an evaluation of economics.

8.16.7 Freezing

Freezing is a process where pure water collects in crystals on the surface of the wastewater while the impure compounds remain in solution. When ice crystals are removed and thawed, the water is very pure. Although the process is usually considered demineralization, it also is capable of removing organic materials from water. Sand and diatomaceous earth filtration and air for foam removal are considered necessary preliminary steps before freezing. There are two types of systems in use; vacuum freeze vapor compression and refrigerant vaporizing.

A few small vacuum freeze vapor compression plants have been erected in the U.S.A. and abroad for desalinization of seawater, but have not had enough service to develop any useful histories.

Although none of the freezing plants has been used in textile wastewater treatment, its use appears attractive to the textile industry because of its tolerance of high levels of salts, organics, suspended solids, and other materials in the feed water. There is insufficient information concerning capital cost, maintenance cost and reliability.

8.16.8 Spray Irrigation

The use of spray irrigation as a method of treating liquid wastes is not a new one. It was used in this country as far back as 1928. Most spray irrigation systems use domestic sewage effluents to irrigate agricultural lands. In the past decade, irrigation with industrial wastewaters has grown more popular. To date, most of the installations have used food processing wastes and organic chemical wastes. The first few inches of soil will biologically degrade the wastes. Effective treatment with wastes having extremely high BOD and TSS values has been proven. Operations at 0° F have been reported. Though no data has been found as to treatability by land application of textile wastes, it would appear that this method is certainly a viable option. In fact, it may prove to be the most economical method of complete treatment available.

Industrial wastewaters having little or no pretreatment have been successfully sprayed. (When sanitary waste is present, chlorination is required). Application can be made into open fields where grasses are planted and periodically harvested or into wooded areas where evapotranspiration effects are high. Pretreatment would consist of screening, flotation for removal of grease, chemical coagulation of solids, and aeration in a holding pond. Another possibility is overland flow using terraced plots.

Regardless of which application methods are investigated, a comprehensive site investigation study including climatology, geology, hydrology, topography, and agronomy will have to be made with subsequent pilot plot studies. Of major concern will be potential ground water contamination, toxic effects from build up of metals, and offensive odors. Nitrogen levels will also be an important consideration because insufficient nitrogen for plant growth will necessitate chemical fertilization; conversely, excess nitrogen beyond ability of plants to utilize and store it will be detrimental. A pH of 5.5 to 7.5 should be maintained which would mean neutralization may have to be practiced by a number of mills. Grease and oil removal is essential for satisfactory operation of the sprinkling equipment, thus questioning the suitability of this method for category 1 (wool scouring).

8.16.9 Algae Harvesting

Harvesting of algae removes nitrogen from wastewater. Waste effluent is usually deposited in ponds where the algae are then removed from the wastestream by microstraining or other filtration techniques.

Although this process is theoretically feasible where large quantities of nitrate are to be removed, it may be necessary to supplement the untreated waste with carbon dioxide to achieve complete nitrogen removal.

The major disadvantages of this process are the large land area requirement and the problems and costs associated with the harvesting and disposal of the algae. The harvested algae, after drying, has some value as an animal feed supplement due to its very high protein content. Research on this subject is presently underway in Japan.

8.17 Upgrading Existing Facilities

This section is intended as a guide to possible alternative methods of upgrading existing treatment facilities in an attempt to meet more stringent effluent requirements. Upgrading to increase hydraulic and/or organic loadings due to increased plant production will not be discussed.

Upgrading textile mill effluents will generally involve the following regulatory stipulations:

- Increased BOD, TSS and COD removal
- Reduction of Chromium, Phenol and Sulfide
- Color Removal

For those mills classified as water quality limited, the regulations are generally more stringent and may include any or all of the following limits:

- Disinfection
- Maintain minimum D.O.
- Remove ammonia – nitrogen
- Remove phosphorus
- Reduce heavy metals including zinc, copper, antimony, lead, etc.

Existing facilities will require modifications and/or new additions to meet specific limits. Tables 8-28 through 8-31 are presented to illustrate some possible methods of upgrading commonly employed present day facilities.

TABLE 8-28

UPGRADING EXISTING FACILITIES
(Increase BOD, TSS Removal)

Existing Facilities	Modification or Addition
1. Aerated lagoon	a. Add one or two lagoons and operate in series providing sufficient aeration of 0.2 to 0.4 HP/1000 cu. ft. volume. b. Modify existing parallel lagoons to series system. c. Modify to activated sludge extended aeration by recycle of sludge from clarifier to aeration basin. d. Modify to activated sludge system and polish effluent by mixed media filtration.
2. Trickling filters	a. Use of fine mesh screening to eliminate lint and short fiber to increase filter efficieny. b. Modify trickling filter for use as a roughing filter and add activated sludge system. c. Increase recirculation rate from clarifier to trickling filter. d. Modify existing single-stage trickling filter to two-stage trickling filter. e. Change stone to synthetic filter media.
3. Secondary treatment (activated sludge)	a. Add equalization basin (with mixing) in front of aeration basin. b. Increase recirculation from clarifier to aeration basin. c. Add clarifier to decrease overflow rate of existing clarifier and increase capability of BOD, TSS removal. d. Add mixed-media filtration following final clarifiers. e. Polish effluent by adding polishing pond following final clarifiers. f. Add powdered carbon as a catalyst in aeration basin to increase efficiency. g. Add nutrient prior to entering aeration basin if the system is nutrient deficient.
4. Stabilization pond	a. Modify stabilization pond to aerated lagoon system. b. Add aerated lagoons, operate in series and use existing stabilization pond as polishing pond.

TABLE 8-29

UPGRADING EXISTING FACILITIES

(Increase Color Removal)

Existing Facilities	Modification or Addition
1. Aerated lagoon	a. Add equalization basin followed by flocculation and settling basins ahead of modified series aerated lagoon system.
	b. Add activated carbon as a catalyst.
2. Trickling filter	a. Add chemical coagulation system consisting of rapid mix, flocculation and clarifier following modified trickling filter system.
3. Secondary treatment (activated sludge)	a. Add chemical system following modified activated sludge system.
	b. Add activated carbon as a catalyst.
4. Stabilization pond	a. Add equalization basin followed by chemical coagulation system ahead of modified stabilization pond.

TABLE 8-30

UPGRADING EXISTING FACILITIES

(Disinfection Requirement)

Existing Facilities	Modification or Addition
1. Aerated lagoon 2. Trickling filters 3. Secondary treatment (activated sludge) 4. Stabilization pond	a. Segregate sanitary wastes and treat separately. b. Add chlorine contact chamber and chlorine feed facilities. c. Add ozonation.

TABLE 8-31

UPGRADING EXISTING FACILITIES

(Maintain Required D. O. Concentration)

Existing Facilities	Modification or Addition
1. Aerated lagoon 2. Trickling filters 3. Secondary treatment (activated sludge) 4. Stabilization pond	a. Add gravity reaeration channel prior to entering the receiving stream. b. Add mechanically mixed reaeration basin.

8.18 Laboratory Requirements

An integral part of any wastewater treatment and monitoring program is an adequately equipped and operated laboratory. Many textile mills have quality control laboratories located in the manufacturing plant and, in some cases, with modifications and additions, this laboratory may also function for wastewater analysis.

The following sections will present recommended laboratory tests and associated equipment required for presentation of effluent analysis to regulatory authorities as well as tests suggested as part of the treatment process control program. Federal or State authorities may require different test frequencies as listed in individual NPDES permits. Also discussed are design considerations for the construction and equipping of a laboratory and information regarding reporting of laboratory test results. Typical required effluent performance tests are shown in Table 8-32 below. Additional tests used for control of the treatment facility are suggested in Tables 8-33 and 8-34.

TABLE 8-32

TYPICAL PERFORMANCE OF EFFLUENT REQUIRED FOR REGULATORY AGENCIES

Item	Test Frequency	Method of Sample	Major Equipment*
BOD	2/week	24 Hr. Composite	BOD Incubator, Distillation Apparatus
Total Suspended Solids	3/week	24 Hr. Composite	103°C Oven, Desiccator, Analytical Balance
COD	2/week	24 Hr. Composite	Heating Mantle, Triple Beam Balance
Oil & Grease	1/week	24 Hr. Composite	103°C Oven, Desiccator
Total Chromium	1/week	24 Hr. Composite	Analytical Balance, Spectrophotometer, Water Bath
Phenol	1/week	24 Hr. Composite	Analytical Balance, Spectrophotometer, pH Meter
Sulfide	1/week	24 Hr. Composite	Spectrophotometer (if use methyl blue photometric)
Color	2/week	24 Hr. Composite	Spectrophotometer
Fecal Coliform	Daily	Grab	Analytical Balance, Water Bath, Filtration Apparatus
pH	Continuous	Sense Continuously	Monitoring Instrumentation Including Sensors, Transmitters and Recorders
Flow	Continuous	Sense Continuously	
Temperature	Continuous	Sense Continuously	

*Major equipment suggested has been selected based upon needs of regulatory agencies and control necessary to achieve reasonable plant efficiency. Miscellaneous equipment, expendables, glass and plasticwares and test kits have not been listed since they are usually for general laboratory uses and not dependent on the type of tests.

Guidelines for these items are available in EPA Publication "Estimating Laboratory Needs For Municipal Wastewater Treatment Facilities", June, 1973.

TABLE 8-33

ADDITIONAL TESTS SUGGESTED FOR PROCESS CONTROL, COST CONTROL, AND HISTORICAL KNOWLEDGE

Item	Test Frequency	Method of Sample	Major Equipment*
D. O.	Daily	24 Hr. Composite	Oxygen Meter, Oxygen Probe and Accessory Kits
NH_3-N	1/week	24 Hr. Composite	Analytical Balance, Spectrophotometer
Organic-N	1/week	24 Hr. Composite	Analytical Balance, Kjeldahl App. Spectrophotometer
NO_3-N	1/week	24 Hr. Composite	Filtration, Water Bath
Total Phosphorus	1/week	24 Hr. Composite	Hotplate, Spectrophotometer
Turbidity	Continuous	Sense Continuously	Turbidimeter
Total Solids	2/week	24 Hr. Composite	103°C Oven, Desiccator, Steam Bath
Total Volatile Solids	2/week	24 Hr. Composite	Muffler Furnace, Desiccator, Analytical Balance
Dissolved Solids	2/week	24 Hr. Composite	(Total Solids) (Total S. S.)
Alkalinity	2/week	24 Hr. Composite	Stirrer Hotplate (Magnetic), pH Meter

*Major equipment suggested has been selected based upon needs of regulatory agencies and control necessary to achieve reasonable plant efficiency. Miscellaneous equipment, expendables, glass and plasticwares and test kits have not been listed since they are usually for general laboratory uses and not dependent on the type of tests.

Guidelines for these items are available in EPA Publication "Estimating Laboratory Needs For Municipal Wastewater Treatment Facilities", June, 1973.

TABLE 8-34

LABORATORY TESTS OF AERATION COMPARTMENTS IN THE ACTIVATED SLUDGE SYSTEM PLANTS

Item	Test Frequency	Method of Sample
Mixed Liquor D. O.	Daily	Grab
Mixed Liquor Suspended Solids	2/week	24 Hr. Composite
Settleability of Activity Sludge	5/week	Grab
Sludge Volume Index	2/week	Grab
Plant Loading lb/BOD/1000 cu. ft.	2/week	24 Hr. Composite
Return Sludge MLSS	Daily	Grab

8.18.1 Laboratory Facilities

When planning wastewater laboratories it is suggested the following items be considered:

8.18.1.1 Location

- Ground level
- Accessible to all sample points
- Northerly exposure to light
- Away from vibrating machinery

8.18.1.2 Space

- Floor space – 180 sq. ft. minimum (EPA) and non-glare (Ten states 400 sq. ft. minimum)
- Bench area – must be 40% of floor area. If 2 persons work add 100 sq. ft. or more
- Aisle width between work benches must be at least 4 feet
- Ceiling height – 8.5 feet minimum

8.18.1.3 Materials of Construction

- Floor, bench top, shelving, cabinets must be highly acid, alkali, solvent and salt resistant, vinyl or rubber
- Walls – ceramic tile or empty coated concrete block
- Ceiling – acoustic tile

- Windows – non-glare type
- Doors – strong, permit a straight egress from the lab and must not be swing doors

8.18.1.4 Cabinet & Bench Top

- Wall-hung cabinets must be 30-inch from bench top
- Bench-top height should be 36-inch. Sit-down bench top should be 30-inches high

8.18.1.5 Hoods

8.18.1.5a Fume Hoods

- Location – should be located where air disturbance at the face of the hood is minimal
- Materials should be plastic or equally resistant material. Sash should be provided. Sliding horizontal or vertical door may be used in sash
- One cup sink should be provided inside the hood. All switches, electrical outlet, utility and baffle adjustment handles should be explosion proof
- Exhaust – 24-hour capability should be provided with buzzer indicating exhaust fan failure failure

8.18.1.5b Canopy Hoods

Should be installed over the bench top area where hot plate, steam bath and other equipment is used.

8.18.1.6 Sinks

- Minimum 3 sinks, 2 of them should be double well with drainboards and 1 cup sink
- Sinks should be constructed of material highly resistant to acids, alkalies, solvents and salts. In addition, they should be abrasion and heat resistant, non-absorbent and light in weight

8.18.1.7 Ventilation and Lighting

- Laboratories should be separately air conditioned
- Separate exhaust ventilation should be provided
- Good lighting, free from shadows for reading dials, meniscuses, etc.

8.18.1.8 Power

- All electrical lines coming into the laboratory should be controlled with CVS harmonic neutralized type transformer to eliminate line fluctuation
- The 220 volt line should be regulated for higher voltage requirements

8.18.1.9 Gas and Vacuum

- Natural gas should be supplied to the laboratory
- Provide adequate vacuum pumps

8.18.1.10 Safety

Safety equipment must be provided and easy to reach when needed.

- Eye wash – irrigator type, face wash type or hand held spray
- Safety shower
- First aid kit – industrial type
- Fire extinguisher
- Fire blanket w/wall case
- Safety cabinet – proper storage of hazardous chemicals for fire prevention
- Safety ladder

8.18.2 Reporting Laboratory Results

When reporting laboratory analytical results, the following tabulation is suggested as a guide to recording values:

TABLE 8-35
REPORTING LABORATORY RESULTS

Parameter	Range	Report to Nearest	
		mg/l	lb/1000 lb product
BOD	0-9.9 mg/l	0.1	0.01
	10-499 mg/l	1	0.1
	500-1000 mg/l	10	1
Solids	0-99.9 mg/l	0.1	0.1
	100-1000 mg/l	1	1
COD	0-9.9 mg/l	0.1	0.1
	10-1000 mg/l	1	1
Oil and Grease	0-99 mg/l	1	0.1
	10-100 mg/l	10	1
Total Chromium	0-9.9 mg/l	0.01	0.01
Phenol	0-9.9 mg/l	0.01	0.01
Sulfide	0-9.9 mg/l	0.01	0.01
NH_3	0-2 mg/l	0.01	0.01
	2-10 mg/l	0.1	0.1
Organic-N	0-2 mg/l	0.01	0.01
	2-10 mg/l	0.1	0.1
NO_3-N	0-10 mg/l	0.01	0.01
Total Phosphorus	0-10 mg/l	0.01	0.01
Alkalinity	—	1	1
D. O.	—	0.1	
pH	0-14 mg/l	0.1 unit	0.1 unit
Color	—	10 ADMI	10 ADMI
Fecal Coliform	MPN Technique	10/100 ml	10/100 ml

8.19 References

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CHAPTER 9

AIR POLLUTION

9.1 Introduction – Emission Sources

The textile industry has not, by the nature of its operations, been one of the major sources of pollution in the United States, and its air pollution problems have been considerably less severe than its water pollution problems. Consequently, this area is only beginning to receive serious and widespread attention within the industry and from the State and Federal enforcement agencies. Most of the air pollution abatement equipment in operation in textile mills today has only recently been installed, and its long-term performance has yet to be evaluated. In addition, the technology has not yet matured, and many of the shortcomings associated with particular generic types of air pollution abatement equipment have been or are now being overcome by specific equipment manufacturers. This chapter can, therefore, only give indications of areas where problems may be anticipated and cannot specify exactly which type of equipment is best for abatement of each type of pollutant under all circumstances.

Relevant regulations and enforcement procedures vary widely from state to state and from region to region in the same state, and many states have not yet developed guidelines for the textile industry. Therefore, users of this manual should consult the appropriate state authorities to find out what is required at their specific locations and what will be required in the future. Federal regulations presently affecting the textile industry are chiefly concerned with stack emissions from incinerators and steam generating plant (1) which are not a problem specific to the textile industry and are, therefore, not the subject of this report.

Emissions from textile processes excluding steam generation fall into four general categories:

- Oil and acid mists
- Solvent vapors
- Odors
- Dust and lint

Oil mists are produced when textile materials containing oils, plasticizers, and other materials that can volatilize or be thermally degraded into volatile substances are subjected to heat. Volatile material is driven off and is condensed on cooling into a blue haze of droplets, most of which are in the range of 0.1 to 1 micron diameter.

Since this is about the wavelength range of visible light, a maximum plume opacity is obtained from very low contaminant concentrations. Typical particulate emission codes require particulate stack emission concentrations to be less than 0.02 grain/SCF. This can be exceeded by a boil-off rate of 1 pint/hr in 5000 CFM of exhaust giving 0.023 grain/ACF. A tenter frame with a stack exhaust particulate concentration of 0.03 to 0.11 grain/ACF will have a plume of 40 to 60%

opacity before abatement (2). The threshold of opacity is about 0.003 to 0.006 grain/ACF. Fibers and lint are usually present in the mist also.

Texturizers produce the cleanest oil mists, consisting mainly of spinning oils, which are relatively undegraded because of the low temperatures at which texturizing takes place. Exhaust air, which is usually cool, (200 to 250° F) has oil droplet concentrations ranging from 0.008 to 0.09 grain/ ACF. In general, texturizing of fine yarns produces a lower volume of evaporated oil than texturizing of heavy yarns. Oil can be recovered and used for heating, since it has a higher BTU value than number 2 fuel oil. In one instance, an electrostatic precipitator operating at 95% efficiency recovered 350 gal/wk of oil from a 25,000 CFM texturizing plant exhaust (3).

The most common source of oil mists in the textile industry is the tenter frame, which produces oil mists with droplet concentrations of 0.03 to 0.45 grain/ACF. Because of the higher operating temperatures, which range from 300 to 400° F, compounds in tenter exhausts are partially oxidized and, therefore, more odorous and corrosive than otherwise. Exhaust composition is a function of the fabric pre-history, and can contain oils, subliming dyes, carrier residues such as o-phenylphenol and its esters, brighteners, emulsifiers, gylcerides, waxes, fatty acids and fatty acid phosphatides, plasticizers, resins, ethylene oxide, and lower molecular weight fractions of the polymer itself (4). These substances can sometimes solidify in the collection equipment. A typical tenter frame produces 25 to 200 lbs/day of effluent (5), (6). In one instance a tenter frame with a 29,000 CFM exhaust produced 1000 to 1800 gallons of oil per week (7). Similar processes producing oil mists include heat setting and drying.

Plasticizers are driven off from all high temperature processes involving vinyl, such as extrusion, coating, tentering and calendaring. Flame bonding, laminating, coating, drying and curing of carpets and upholstery fabrics volatilizes plasticizers, adhesives, jute oils, etc., producing gummy odorous mists. Particularly troublesome are mists consisting of mixtures of plasticizer and stearic acid produced during heat treatment of latex foam backed carpets and upholstery fabrics. At 400° F, most of the plasticizer, and a considerable proportion of the stearic acid, is driven off.

Oil mist elimination techniques are discussed in Section 9.3.

Acid mists are produced during the carbonizing of wool and during some types of spray dyeing and acetic acid mist dyeing. Because of their corrosive nature, some techniques for oil mist elimination are not applicable to this type of dyeing. They are therefore discussed separately at the end of Section 9.3.

Organic solvent vapors are released during and after all solvent processing operations. The most common use of solvent processing in the textile industry is the use of chlorinated hydrocarbons for dry cleaning. These cannot generally be treated by scrubbing because of their limited solubility in the water. On incineration, they release hydrogen chloride gas. Particulate removal techniques are also inapplicable since the solvents are present entirely in the vapor phase. Solvent dyeing and printing and the application of finishes from solvent solution present similar problems. Complete solvent recovery systems are available, often as an integral part of the solvent processing equipment itself. Solvent recovery by adsorption onto activated carbon is discussed in Section 9.4.

Odors are often associated with oil mists or solvent vapors and are removed by removal of the mist or by recovery of the vapor. In other cases, the odorant is present mainly in the vapor phase and in such small concentrations as to make recovery in a solvent recovery system inapplicable. The most common odor problems of this type are the carrier odors from aqueous polyester dyeing and processes subsequent to it. Resin finishing also produces odors, chiefly of formaldehyde. Other sources of odor are sulfur dyeing on cotton and cotton blends; reducing or stripping dyes with hydrosulfite, bonding, laminating, backcoating; and bleaching with chlorine dioxide. Odor abatement techniques are discussed in Section 9.6.

Dust and fly are produced in the greatest quantity by the processing of natural fibers and synthetic staple prior to and during spinning, and by napping and carpet shearing. To a lesser extent, most other textile processes produce lint, which, while it is not a major pollutant in itself, complicates abatement processes for other pollutants. Its removal as a secondary contaminant will be discussed in Sections 9.2 through 9.6. Removal of dust from otherwise clean air is discussed in Section 9.7.

9.2 Available Abatement Equipment

A wide variety of equipment is available for abatement of the various types of air pollution produced by textile processes. The abatement techniques may be divided into three categories: 1) those that destroy the pollutant; 2) those that collect it in a relatively concentrated "dry" form; and 3) those that wash it from the exhaust into water or some other collecting liquid (see Table 9-1). This section attempts to provide a detailed description of each type of available equipment, to which subsequent sections of this chapter will refer when discussing specific pollution problems. Where coverage is adequate, the reader is referred to the EPA Air Pollution Handbook, 2nd Edition (8), and to Perry's Chemical Engineers' Handbook, 5th Edition (9), standard references which this discussion does not attempt to duplicate.

9.2.1 Incineration and Chemical Destruction

Where applicable, incineration of pollutants has the advantage that it results in their total destruction if carried to completion, the products being H_2O, CO_2, and NO_2. It is also the simplest and most reliable method of pollution abatement, but the high and rising costs of energy makes it the most costly method as well, especially if heat recovery is not employed subsequently. For this reason, it is generally not preferred for exhaust flow rates above 5,000 CFM. It is often used for destruction of previously concentrated exhausts, such as steam stripped solvent from carbon solvent recovery beds and lint laden air from blow-down of lint filters (see Sections 9.5, 9.6 and 9.7).

TABLE 9-1
BASIC AIR POLLUTION CONTROL EQUIPMENT

- Incineration:
  - Open Flame
  - Direct Fume
  - Catalytic Oxidation

- Dry Collectors:
  - Cyclone Separator
  - Filters:
    - Bag House
    - Mist Eliminator
    - High Velocity Fiber Mat
  - Electrostatic Precipitator
  - Absorption

- Scrubbers:
  - Packed Tower
  - Plate Column
  - Spray Tower
  - Inertial Impaction
  - Fluidized Bed
  - Orifice
  - Venturi
  - Water Jet
  - Mechanical
  - Fiber Bed
  - Reinstate
  - Ionizing Wet

Compounds containing only C, H, and O can be oxidized completely to CO_2 and H_2O. Nitrogen will form NO_2 to a significant extent at high temperatures, but this can be disregarded below 3,000° F. Other elements will form solid or gaseous substances that must subsequently be removed by scrubbing; chlorine, bromine, and flourine form HCl, HBr, and HF, respectively, while sulfur, phosphorous, silicon, and metals form their oxides.

Since all substances that can be destroyed by incineration are flammable, care must be taken to prevent their condensation and buildup in the ducts leading to the incinerator. Oil vapors must be kept above their condensation temperature. To maintain the flammable vapor concentration below 25% of the lower explosion limit, the National Fire Protection Association recommends that 10,000 CFM of air (measured at 70° F) be vented with each liquid gallon of evaporated oil or solvent (10). If insufficient air is vented from the particular piece of textile processing machinery to effect this, additional dilution air should be added prior to incineration.

Hydrocarbon oxidation is generally a complex, stepwise process, with aldehydes, ketones, and organic acids as intermediates. Since these are generally more odorous and corrosive than the original emissions, care must be taken to see that incineration is carried to completion.

Three methods of incineration are available: open flame incineration, direct fume incineration and catalytic oxidation. In addition, pollutants can be destroyed chemically by reaction with dry solids. Of the various methods, open flame burning is the least reliable, since the contact time between the flame and the pollutants is usually too short to insure complete destruction. This method can be used only with readily combustible products (2). It can produce soot, carbon monoxide and partially oxidized hydrocarbons that are often more objectionable than the original substance.

Open flame combustion is discussed in detail in the EPA Air Pollution Engineering Manual (8), pages 171-9, to which the reader is referred for design criteria. An energy saving variation of this method of incineration is to use the pollutant laden exhaust as a source of combustion air for a boiler or furnace. This allows a considerable savings in incinerator capital costs and fuel costs, but it limits plant flexibility by requiring operation of the boiler at all times when the exhaust is being produced. Care must also be taken to avoid flashback or condensation in the ducts leading to the boiler and to avoid fouling of the boiler heat exchange surfaces with the products of pollutant combustion. Adequate oxygen for boiler fuel combustion must also be assured, both when the exhaust is being fed to the boiler and when it is not. This option is discussed in detail in the EPA Air Pollution Manual, pages 183-9.

Direct fume incineration requires heating of the pollutant-air mixture to 1,400 to 1,500° F for 0.3 to 0.5 seconds, generally in an externally heated combustion chamber. Since liquid, solids and vaporized hydrocarbons are all oxidized completely to water and carbon dioxide, no pre-filter is required for lint removal. Installed costs for direct fume incinerators without heat recovery were approximately $4.00 per CFM in 1975. Heat recovery generally doubles the initial investment and halves the operating cost (see Section 9-4). Direct fume incinerators require very little maintenance (11). However, care must be taken to ensure and maintain proper operating conditions, as discussed above.

Figures 9-1 and 9-2 show the relationships between fuel cost, incinerator inlet temperature, and exhaust volume for a direct fume incinerator operating 8000 hours per year at 1,500° F without heat recovery at 80% efficiency on number 2 fuel oil at $0.30 per gallon. This fuel was selected as the example because of the high sulfur content of most other liquid and solid fuels and the increasing scarcity of natural gas. Figure 9-2 assumes a typical inlet temperature to the incinerator of 300° F.

No credit has been taken for the heating value of the pollutant, since this is dependent on the nature of the process producing the emissions, the material being processed and the operating conditions. Emissions produced by boil-off tend to increase as the process operating temperature is increased, as the boiling point of the volatiles is decreased (by process or product changes), and as the amount of volatile material in the textile is increased. In any event, the total heat value of the pollutants must be kept low to avoid fire and explosion hazards, as discussed previously. Where process improvement is possible, it is wisest to reduce the pollutant

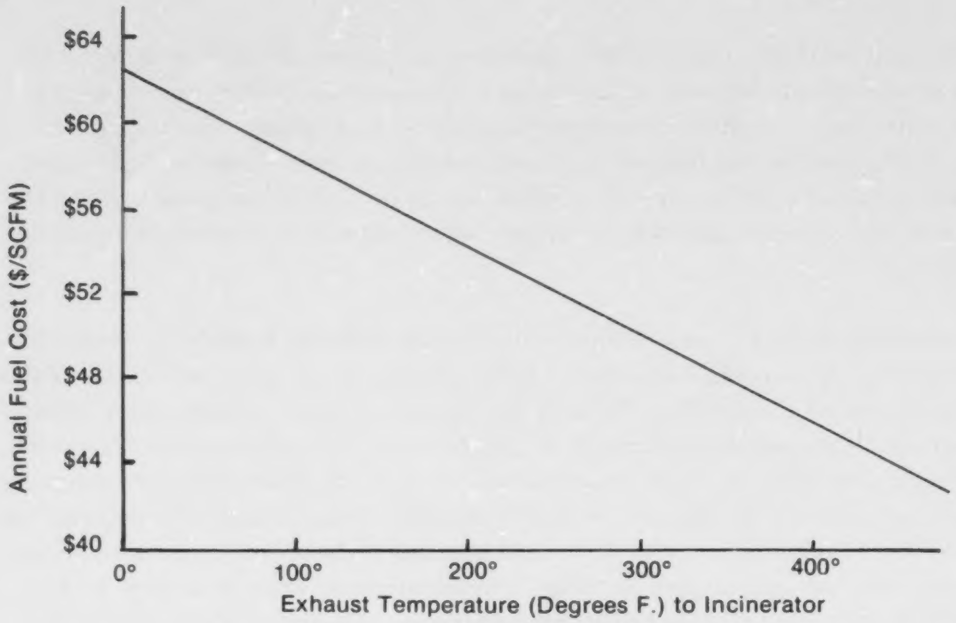


FIGURE 9-1

DIRECT FUME INCINERATION FUEL COSTS WITH NO HEAT RECOVERY, NO. 2 FUEL OIL AT $.30/GAL.

Source: Lockwood Greene Engineers, Inc.

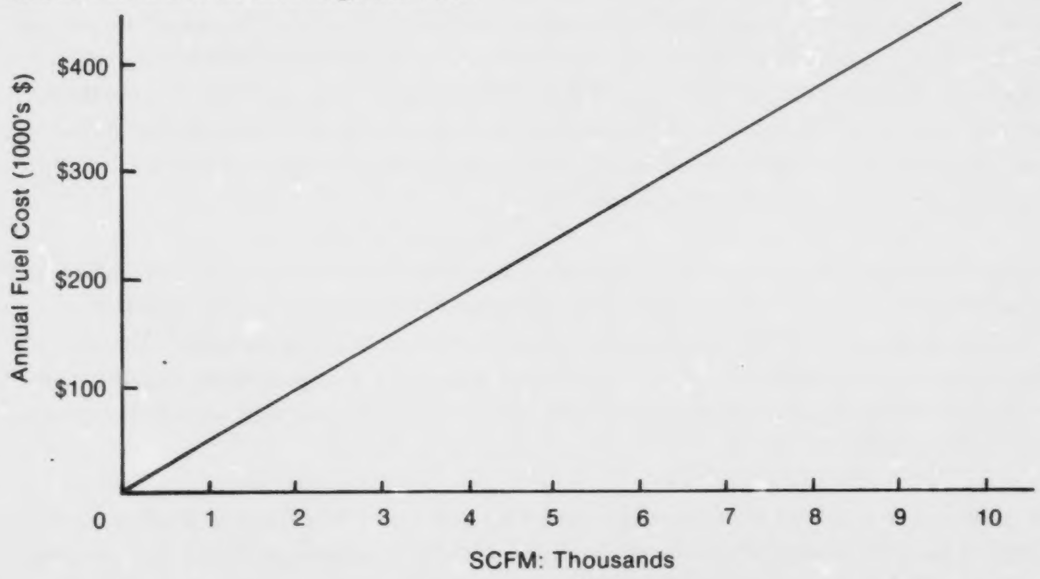


FIGURE 9-2

TOTAL FUEL COSTS FOR DIRECT FUME INCINERATION WITHOUT HEAT RECOVERY, EXHAUST AT 300°F, NO. 2 FUEL AT $.30/GAL.

Source: Lockwood Greene Engineers, Inc.

concentration in the incinerator rather than to take a heating credit for it, since most volatile solvents and plasticizers are considerably more expensive than fuel oil.

Catalytic incinerators cost about \$3.50 to \$5.00 per CFM installed (1975 prices) and can be used only for destruction of pollutants that are gaseous at the incinerator operating temperatures. Therefore lint, dust, etc. must be removed from the exhaust with a pre-filter. Impurities in the vapor phase are first adsorbed onto the catalytically active surface where reaction takes place.

The principal advantage of catalytic destruction over other techniques for oxidation of air pollutants is due to the reduced operating temperature. Without heat recovery, the fuel costs for any process involving the heating of process air are given by the expression:

$$\text{Annual cost/SCFM} = \frac{\$2900 \ (T_H - T_I)}{114{,}000 - 27\,T_H} \qquad (9.1)$$

Here, T_H and T_I[a] are the air outlet and inlet temperatures (° F), and the assumptions used are those used in deriving the relations graphed in Figures 9-1 and 9-2.

Catalytic oxidation of organic pollutants takes place at temperatures at or below 850° F, depending on the catalyst and the pollutant. Since operating temperatures are lower than for other forms of incineration, fire and explosion hazards are also reduced, though this should not be relied upon in system design because of the possibility of ignition by hot spots in the catalyst bed. Oxides of nitrogen can also be destroyed catalytically at these low temperatures (12).

Catalytic oxidation causes an increase in the temperature of the exhaust gas that is given in steady state by the relationship:

$$\Delta T = \frac{X \Delta H}{C_p} \qquad (9.2)$$

where:

ΔT = temperature rise (° F)
X = pollutant weight fraction in the inlet gas
ΔH = pollutant heat of combustion, BTU/lb
C_p = Specific heat of exhaust stream after combustion, BTU/lb ° F.

If the exhaust stream is virtually pure air, the heat capacity is 0.25 BTU/lb ° F, and equation 9.2 simplifies to:

$$\Delta T = 4X \Delta H \qquad (9.3)$$

---

[a] All symbols are defined in Table 9-2 located at the end of this Chapter (page 9-71).

If the incinerator inlet and outlet temperatures are known, the inlet pollutant concentration can be determined, assuming complete combustion. The response time of the outlet temperature is sufficiently rapid that it can be used to regulate the flow of additional dilution air to the incinerator (13). The 1973 edition of the National Fire Protection Association handbook states that for each gallon of organic solvent evaporated, 10,000 cfm of air at 70° F should be exhausted (14). At a typical Δ H of 120,000 BTU/gal, this gives a temperature rise of about 660° F across the catalyst.

Oxidation catalysts are generally platinum group metals (since these give the lowest ignition temperature), or copper or silver. The required surface area for platinum group metals as oxidation catalysts is approximately 0.2 $ft.^2$/CFM, but in difficult situations, surface areas as high as 0.5 ft^2/CFM may be required (12). To maximize the surface area obtainable per pound of the expensive catalyst, the active metal is generally deposited on a cheap, more or less inert support, such as silica, alumina, activated carbon or a ribbon of inexpensive metal. The support is often made porous to increase its surface area per cubic foot. Figure 9-3 shows a typical catalytic incinerator.

Catalysts employed in destruction of emissions should have the following featues: (13).

- Mechanical strength and rigidity: one of the chief causes of catalyst attrition is abrasion to irretrievable fines.
- Thermal stability, both in the range from room temperature to the operating temperature and above that to the temperatures encountered in catalyst regeneration.
- Thermal conductivity to dissipate heat from areas of high reaction rate to prevent hot spotting.
- Resistance to damage by water. Most exhausts contain water vapor that can condense on the catalyst surface.
- Slow rate of deactivation. Catalyst reactivation or replacement costs are substantial, running as high as $1.00/CFM (12).
- Modular element configuration for ease of replacement.
- Easy cleanability, preferably by washing.

Decomposition catalysts, which have limited use for decomposition of relatively unstable substances, include manganese dioxide or cupric oxide on activated carbon. Oxides of chromium, molybdenum and tungsten supported on carbon perform intermittently. The pollutant is adsorbed onto the carbon at low temperature (below 120° F), and then the temperature is raised to cause catalytic surface oxidation (11).

The most serious problem with catalytic emission destruction is loss and deactivation of the catalyst. Catalyst losses are due primarily to abrasion, which is expecially severe with heavy particulate loading. Deactivation occurs because of clogging with particulates, carbonization on the catalyst surface or in the pores, and poisoning. Metallic and organometallic vapors of arsenic,

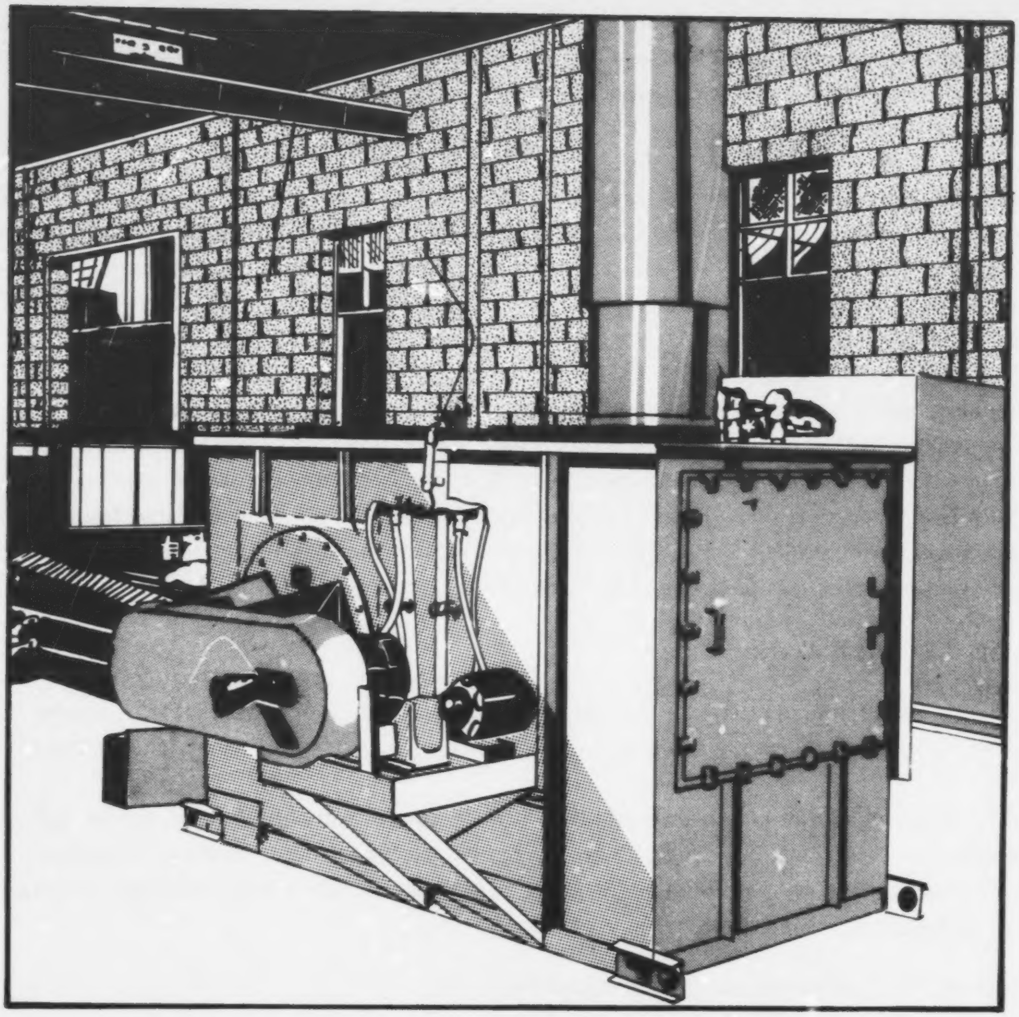


FIGURE 9-3

CATALYTIC INCINERATOR

Source: Catalytic Products International Inc.

lead, zinc, and mercury are the most common catalyst poisons, though most textile process emissions do not contain these.

Poisons can often be eliminated before contact with the catalyst. They are sometimes removed by essentially irreversible adsorption in a small sacrificial bed of catalyst or decomposed to more easily treatable substances. Metal-organic compounds, for example, can be broken down into hydrocarbons and solid metal oxides which can be removed by subsequent scrubbing or electrostatic precipitation (13). Other substances requiring subsequent treatment include fly ash, silicones and inorganic salts.

For these reasons, it is necessary to know the composition of the emission before installation of a catalytic system. Regeneration and/or catalyst replacement will always be necessary from time to time, and the frequency of this should be determined in advance. In one application involving the destruction of oil mist from a tenter by catalytic incineration, the catalyst required washing every 6 months and replacement every 3 years (15).

Chemical destruction of some pollutants can be accomplished by reaction with activated alumina impregnated with potassium permanganate, or by activated carbon impregnated with bromine, iodine, lead acetate or sodium silicate. Reaction is stoichiometric and requires a relatively large catalyst surface area. Adsorbents may therefore have to be replaced frequently. Costs are about equivalent to those of a chemical scrubber system, with the scrubber having the advantages of ease of control and replacement of the chemical liquor (11).

9.2.2 Dry Collection Methods

Pollutant destruction, discussed in the previous section, has the advantage that it eliminates the need for subsequent disposal, albeit at the cost of high consumption of energy and/or chemicals.

Dry collection methods concentrate and collect the waste for subsequent reuse, combustion or disposal, but they generally require far less energy than incineration or chemical destruction. In this category fall such methods as filtration, adsorption (generally onto activated carbon), and electrostatic precipitation.

There are four basic methods of particle collection (8):

1. Collision of the particle with a filter surface and subsequent adhesion. This can be due to impingement, whereby the particle collides with the filter because it cannot follow the flow line of the exhaust gas at an abrupt bend because of inertial or gravitational forces, or flow line interception, whereby the particle's flow path itself brings it into contact with the collection surface. This collection mechanism tends to become more efficient as the exhaust velocity and particle size are increased. Particle sizes below about 2 microns have little inertia, and are collected by flow interception, if at all; larger particles can be collected by impaction (defined here as forcible impingement, due to inertial forces).

2. Straining, whereby the particle cannot fit through the pores of the filter medium. This effect increases with particle size and loading of the filter; however, the pressure drop required to obtain a specific volume of exhaust flow also increases as the loading of the filter increases and as its mesh size decreases.

3. Brownian motion: The particles collide with the collection medium because of their random motion caused by the uneven bombardment of air molecules on them. This effect becomes more pronounced as particle size decreases and as exhaust velocity decreases.

4. Electrostatic attraction of the particles to oppositely charged collection plates. This is the mechanism responsible for collection by electrostatic precipitation.

The collection efficiency, η, is defined as the weight fraction of entering particles collected. Since efficiencies generally decrease with decreasing particle size, the overall efficiency of collection cannot be used to predict reduction of plume opacity. The smaller particles (0.1 to 1 micron diameter) which contribute most to the opacity often are a small proportion of the total weight of pollutant. Overall efficiency is related to the efficiency of removal of particles of any given diameter by the expression:

$$\eta = \int_{0}^{D} \left[\eta \quad (D_p) \right] \left[C_d \quad (D_p) \right] dD_p \qquad \text{(9.4) (Reference 16)}$$

(See Table 9-2 (page 9-71) for an explanation of the symbols.) It is also useful to express performances as efficiency obtained per unit of pressure drop according to the expression:

$$Y = \frac{\ln[1/(1 - \eta)]}{\Delta \, Pi} \qquad \text{(9.5) (Reference 9, p 20-78)}$$

9.2.2.1 Gravity and Centrifugal Collectors

Gravity collectors consist generally of long empty rectangular chambers through which the exhaust flows slowly enough to allow the particles to settle out. In the Howard fume arrester, many horizontal plates are arranged as shelves in the chamber to minimize the distance through which the particles must drop. The minimum size of particles that can be completely removed is determined by balancing the required settling time, calculated from the Stokes' law velocity, against the exhaust gas residence time:

$$D_p = \left[\frac{18 \mu g q}{g N_s L_s B_s \, (p_l - p_g)} \right]^{1/2} \qquad \text{(9.6) (Reference 9, p 20-80)}$$

In practice, particles as small as 10 microns can be removed. The pressure drop across these devices is generally a fraction of an inch of water, consisting mainly of entrance and exit losses. Gravity settlers are gradually being replaced by other, more compact, lower cost separators (17), but these settlers still find use as precleaners for coarse dust and fiber removal.

Cyclone separators operate on essentially the same principle as gravity settlers, employing centrifugal force rather than gravitation as the impetus for separation. Figure 9-4 shows a cutaway view of a typical commercially available cyclone. They are generally preferred to gravity settlers for removal of coarse particles and mists because of their smaller size and lower cost. The minimum particle size removable ranges down to 15 to 40 microns for most models, though at least one new model is claimed to remove particles as small as 5 microns (18). Figure 9-5 shows the estimated efficiency of a cyclone of the type shown in the previous figure. As can be seen, greater dry particle removal efficiencies are obtained if the cyclone is used as a pre-filter prior to a cloth bag.

Detailed design and application criteria for cyclones are given in the EPA Air Pollution Manual (8), pp. 91-99, and also Perry's Chemical Engineer's Handbook (9), 5th ed., pp. 21-81 to 21-87.

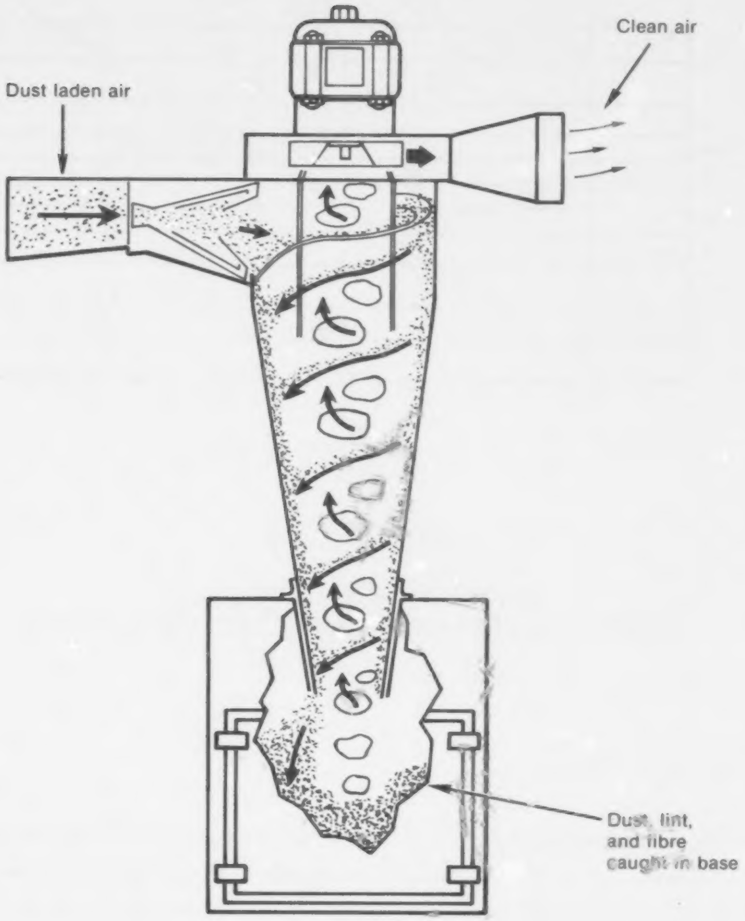

Clean air
Dust laden air
Dust, lint, and fibre caught in base

FIGURE 9-4

CYCLONE SCRUBBER

Source: The Torit Corporation

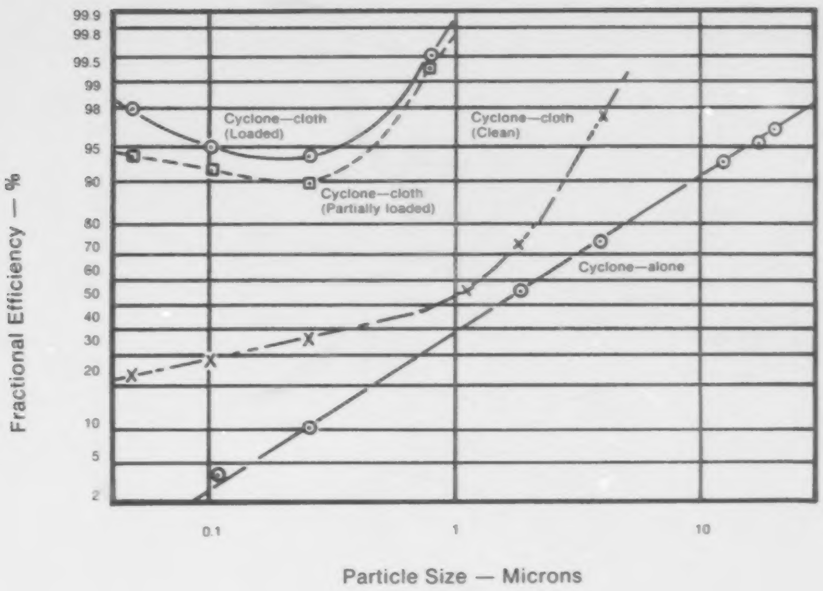


FIGURE 9-5

EFFICIENCY OF CYCLONE WITH AND WITHOUT FABRIC AFTER FILTERS

Source: The Torit Corporation

9.2.2.2 Filters

Filters may be used for particulate removal in cases where the particles are either dry solids that can be easily removed from the filter, freely flowing oils that will drain from the filter, or present in sufficiently small concentration that the collection device can be cleaned or replaced infrequently. For collection of dry dusts down to the submicron range, with 99+% efficiency, bag filters are most commonly used, generally arranged into bag houses. Filtration efficiency and pressure drop through a bag filter are initially low, until a mat of collected material builds up. This mat then performs most of the filtration. Cleaning is performed by mechanical vibration or reverse air flow, usually on an automatic cycle. Cloth bag filters usually operate with a pressure drop of 2 to 6 inches of water and an air-to-cloth ratio of 1 to 8 CFM per ft.^{2} of fabric, though with fine dusts, 3 CFM/ft.^{2} is about the maximum air-to-cloth ratio, since higher air velocities tend to destroy the particulate mat that performs the filtration. Felted fabric bags can be operated at up to 30 CFM/ft^2, since the particulate mat plays a less important part in the filtration, but they are generally operated at 5 to 10 CFM/ft^2. Figure 9-6 shows a typical simple bag house. Detailed design and application criteria for bag houses may be found in the EPA Air Pollution Manual (8), pp. 106-135, and in Perry's Chemical Engineer's Handbook (9), 5th ed., pp. 20-89 to 20-95.

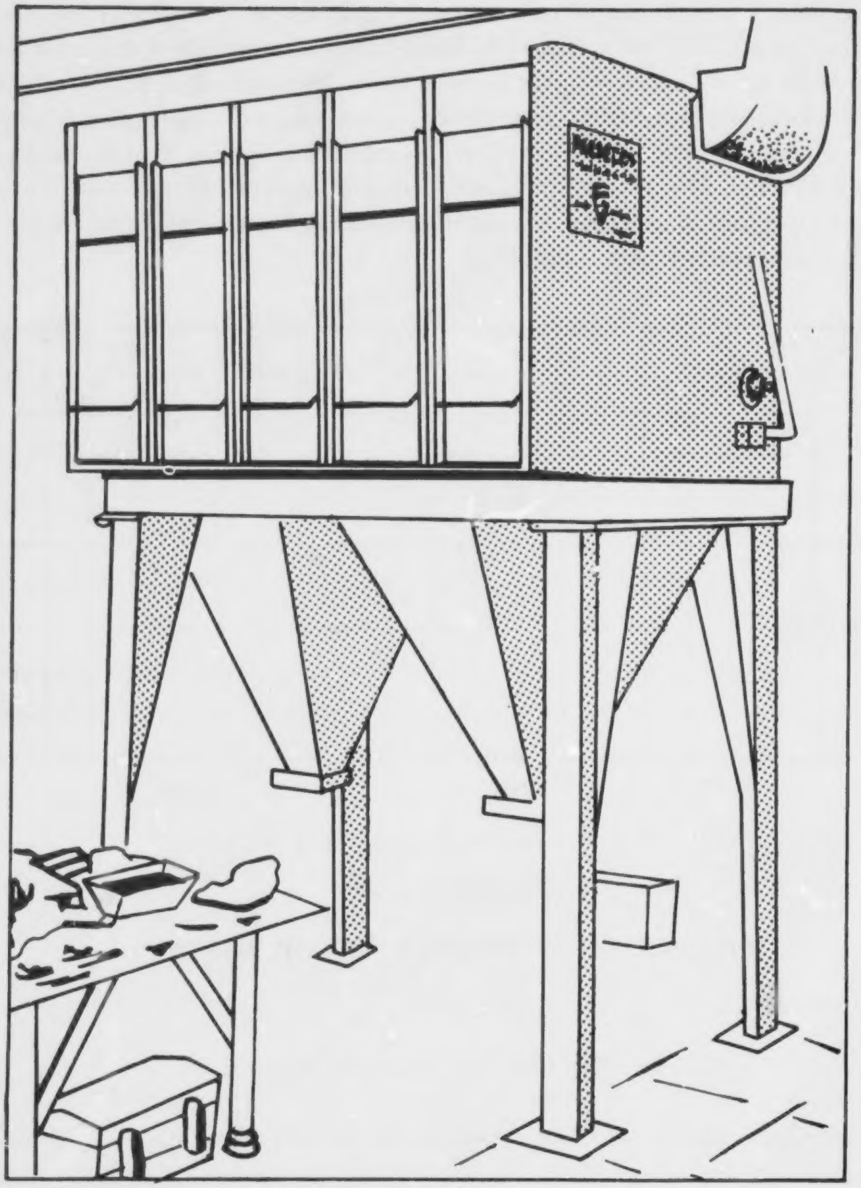


FIGURE 9-6

BAG HOUSE

Source: Sly Manufacturing Company

In the collection of solids, high efficiencies may be achieved due to solids buildup on the filter surface; this mechanism does not apply to aerosols. Figure 9-7 shows a plot of filtration efficiency for oil mists, the most common aerosol produced by textile operations, versus air velocity through one commercial filter. High collection efficiencies are achieved at low air velocities, because the droplets collide with the filter medium due to Brownian motion. Figure 9-8 shows the rate of Brownian displacement of small particles as a function of droplet size. As can be seen, smaller particles migrate further in a given amount of time, making their probability of collision with the fibers and capture greater than with large particles. At high velocities, impaction is the principal collection mechanism, and efficiencies again rise until the air velocity becomes so high that re-entrainment is a problem.

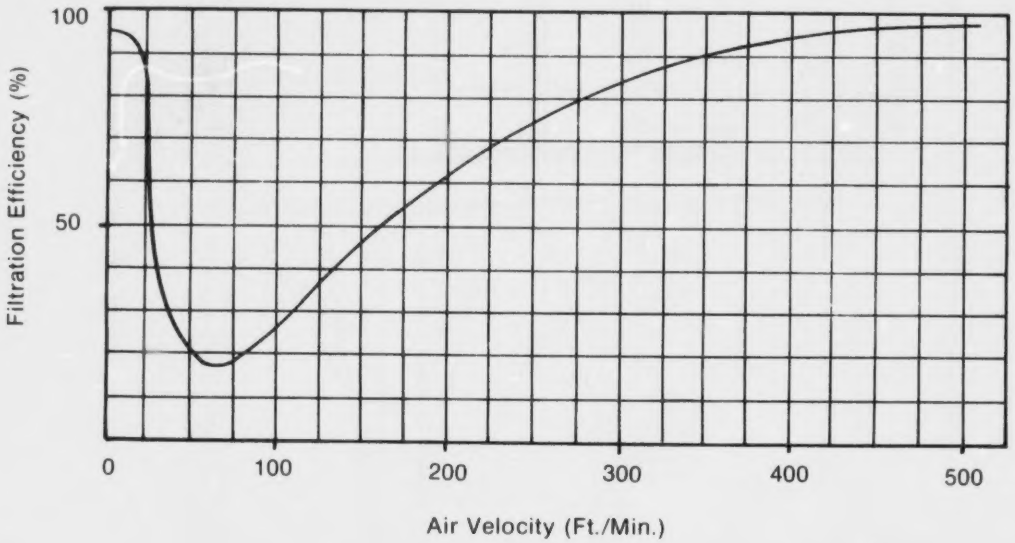


FIGURE 9-7

FILTRATION EFFICIENCY FOR OIL MISTS

Source: Reference 19

9.2.2.2a High Efficiency Fiber Mist Eliminators

Operating at the lower end of the velocity range are the high efficiency fiber mist eliminators. Figure 9-9 shows a typical set-up. Mist laden gas flows radially through a fiber bed, which removes the droplets by impaction, interception and, in the case of the small particles, Brownian motion. The droplets condense in the fiber matrix into a liquid film that flows downward and inward to a collection point.

Vapor velocities are typically 15 to 40 ft/min., for a pressure drop of 5 to 15 inches of water, and a collection efficiency of 95 to 99+% on all particles smaller than 3 microns. Collection efficiency for fine droplets increases slightly with decreasing droplet size and decreasing air flow rate, so

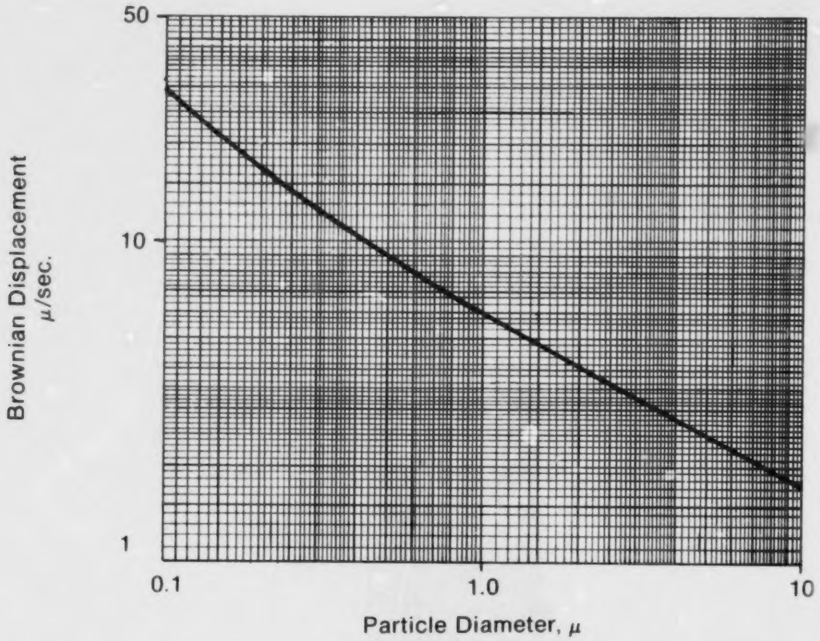


FIGURE 9-8

BROWNIAN DISPLACEMENT OF SMALL PARTICLES

Source: Reference 20

there is no turn-down problem. Figure 9-10 shows some of the filter elements available for high efficiency and high velocity mist eliminators. The high efficiency cartridges are large, typically 24" in diameter and 8 ft. high. Each element of this size weighs about 300 lbs. clean and 700 to 800 lbs. saturated and costs $400 to $2000 (1975 prices).

Since the collection efficiency for large particles (above 3 microns diameter) will be virtually 100% at all reasonable flow rates, and the efficiency of collection of small particles increases with residence time, increasing the filter volume of a high efficiency mist eliminator increases the collection efficiency, but of course the installed cost also increases. Filter volume can be increased, within reason, by increasing either the bed depth or the flow cross section. Increasing the bed depth increases the required pressure drop, but increasing the flow cross section decreases the pressure drop because it decreases the linear velocity. Therefore, it is generally wiser to add a second unit for greater efficiency than to substitute a single larger unit for a small one. Unlike the case of scrubbers, the efficiency of high efficiency fiber mist eliminators is not increased by increasing the pressure drop. This merely increases velocity and decreases residence time.

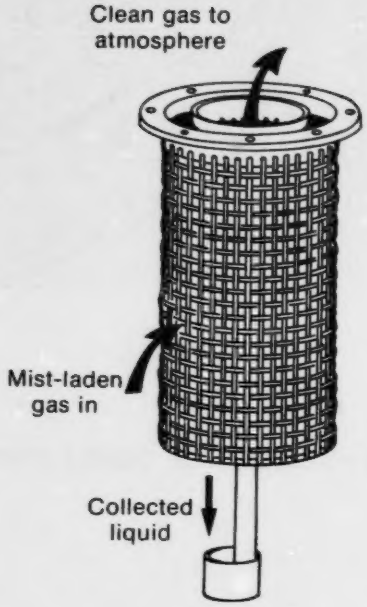
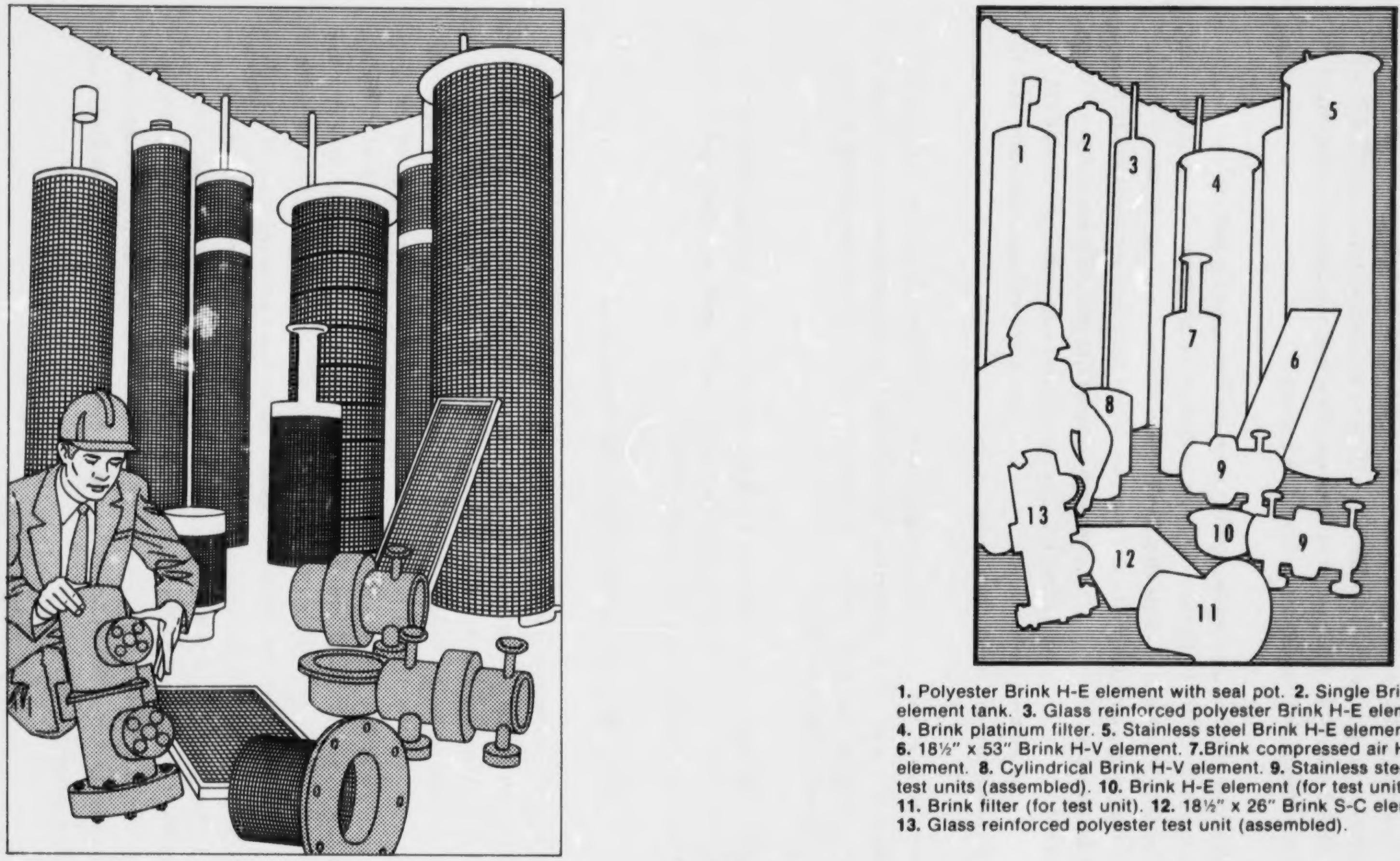

Clean gas to atmosphere
Mist-laden gas in
Collected liquid

FIGURE 9-9

HIGH EFFICIENCY FIBER MIST ELIMINATOR

Source: Monsanto Enviro-Chem Systems, Inc.



1. Polyester Brink H-E element with seal pot. **2.** Single Brink H-E element tank. **3.** Glass reinforced polyester Brink H-E element. **4.** Brink platinum filter. **5.** Stainless steel Brink H-E element. **6.** 18½" x 53" Brink H-V element. **7.**Brink compressed air H-E element. **8.** Cylindrical Brink H-V element. **9.** Stainless steel test units (assembled). **10.** Brink H-E element (for test unit). **11.** Brink filter (for test unit). **12.** 18½" x 26" Brink S-C element. **13.** Glass reinforced polyester test unit (assembled).

FIGURE 9-10

HIGH EFFICIENCY AND HIGH VELOCITY FILTER ELEMENTS

Source: Monsanto Enviro-Chem Systems, Inc.

In 1975, installed costs were $2.00 to $4.00 per CFM for total systems using high efficiency fiber mist eliminators to clean up texturizer exhausts, where no cooling is necessary, and $3.25 to $8.00 per CFM to clean up tenter frame exhausts. A 10,000 CFM system operating at a 14 in. to 15 in. pressure drop requires a 40 HP fan, with a power consumption of 15 KW, or $0.30 per hour at $0.02 per KWH. For proper system specification, the particle size distribution, loading, and condensation temperatures should be known.

High efficiency fiber mist eliminators require prefiltration for lint removal and pre-cooling of the exhaust air, generally to 110° F. Because of their weight, they are generally mounted on the ground rather than on the roof. This also facilitates replacement of the elements. Cleaning is performed, if necessary, by steam, hot air or water. When they become completely fouled, the elements must be replaced. However, frequent replacement has generally not been necessary. One installation on a dryer has been operating for 2 years without element replacement (7). Another mill has used mist eliminators on tenter frames, operating at exhaust velocities of 5 to 10 CFM/ft^2, with element changes every 2 to 3 years (21).

With gummy or waxy condensates, operating temperatures should be adjusted to avoid solids deposition. Phenolic resins may cause problems. One installation, operating on a vinyl plasticizer mist, has reported gradual loss in collection efficiency, possibly due to channeling and bypassing caused by settling of the fiber bed.

Although they cannot start fires, mist eliminators will be ruined by fires started elsewhere in the exhaust system. For this reason, they should be equipped with spark arrestors, quick acting bypass dampers or washers that will activate in case of fire.

9.2.2.2b High Velocity Fiber Mist Eliminators

High velocity fiber mist eliminators generally consist of a fiber mat held between two screens. They operate in the upper region of high efficiency aerosol collection, where the primary mechanisms are interception and impingement. Efficiency of collection increases both with pressure drop and with droplet diameter. Collection is generally 100% for particles over 3 microns. For particles under 3 microns diameter, collection efficiency depends on the design of the filter. One company (22) advertises two types: A high velocity (H-V) filter and a spray cleaner. Both are designed to operate at 400 to 500 ft/min linear velocity, but the H-V filter operates at 6 to 8 inches of water pressure, with a collection efficiency of 85 to 97% for 1 to 3 micron particles, 50 to 85% for 0.5 to 1 micron particles, while the spray cleaner has a pressure drop of 1 to 2 inches of water and a collection efficiency of 15 to 30% for particles of less than 3 microns diameter. The two filter packings are interchangeable, allowing for experimentation at relatively low cost. Filters of this type are often used after scrubbers, cyclones and other devices that produce sprays of relatively large droplet size. Some varieties are irrigated with water or another liquid, allowing them to serve as filters for coarse droplet removal and as packed towers for removal of gases and soluble dusts.

For removal of oil mists, with particle sizes in the range of 0.1 to 1 Micron, pressure drops of 25 to 35 inches of water are required. Installed costs (in 1974) ranged from $0.50 to $3.50 per CFM (11). Filter replacement costs (1975) for one such unit were reported to be $600 to $1200 per 10,000 CFM per year (19). In this unit, which is especially suited to removal of sticky aerosols of low droplet concentration, the filter medium is supported on a drum that indexes as the filter becomes clogged. The filter is fed across the drum from roll to roll and thrown away after use. Figure 9-11 shows a drawing of this setup.

Pre-filtration for removal of lint is recommended and pre-cooling of the exhaust is necessary. Post-filtration may also be necessary for re-entrained particles, though their size will be larger than those in the original mist.

9.2.2.2c Other Types of Filters

A large number of self-cleaning filters are available, mostly for the removal of dry dusts and fly. Bag houses are often equipped with automatic blowers on the clean air side that sweep each bag, continuously cleaning it one small area at a time. Rotating drum filters are also used, whereby lint-laden air is fed to the inside of the drum and removed from one area of the outside, or vice-versa. As the filtering position becomes clogged, the drum indexes, exposing a fresh section to the air stream, and the collected material is removed for disposal by pressure or suction.

Another type of self-cleaning filter consists of a flat surface that is continually cleaned by a vacuum nozzle that sweeps its entire surface. This is usually used for removal of finer particles than a rotating drum. One system has a swept filter following a rotating drum. Exhaust from the cleaning system of the swept filter is recycled to the input of the rotating drum, where it is caught and removed in the fiber mat that collects on the rotating drum.

Other types of self-cleaning filters are available. In many systems, filter fabric is reeled from roll to roll across the exhaust stream. This setup is similar to a rotating drum, but the clogged filter medium is collected on the output roll for off-line cleaning or disposal. In another type, a steel mesh wheel is slowly rotated with the bottom passing through a cleaning oil bath. Such a setup would be useful for removal of oily lint which would clog other types of self-cleaning systems. Replaceable filters or filters with elements that must either be replaced or manually washed, have a low installation cost, but a high operating cost in situations where large quantities of particulates must be removed. They are used chiefly for removal of small amounts of lint from an air stream, often as pre-filters prior to oil mist abatement systems, heat exchangers or solvent recovery systems (see Section 9.3 through 9.6) Their advantage is low initial cost, durability and simplicity. Fiberglass or fiber elements are used for low temperature applications, while for temperatures above 250° F, as with tenter frame exhausts, steel mesh filters are preferred. When loaded, these filters are manually cleaned and an adhesive is reapplied to improve collection efficiency.

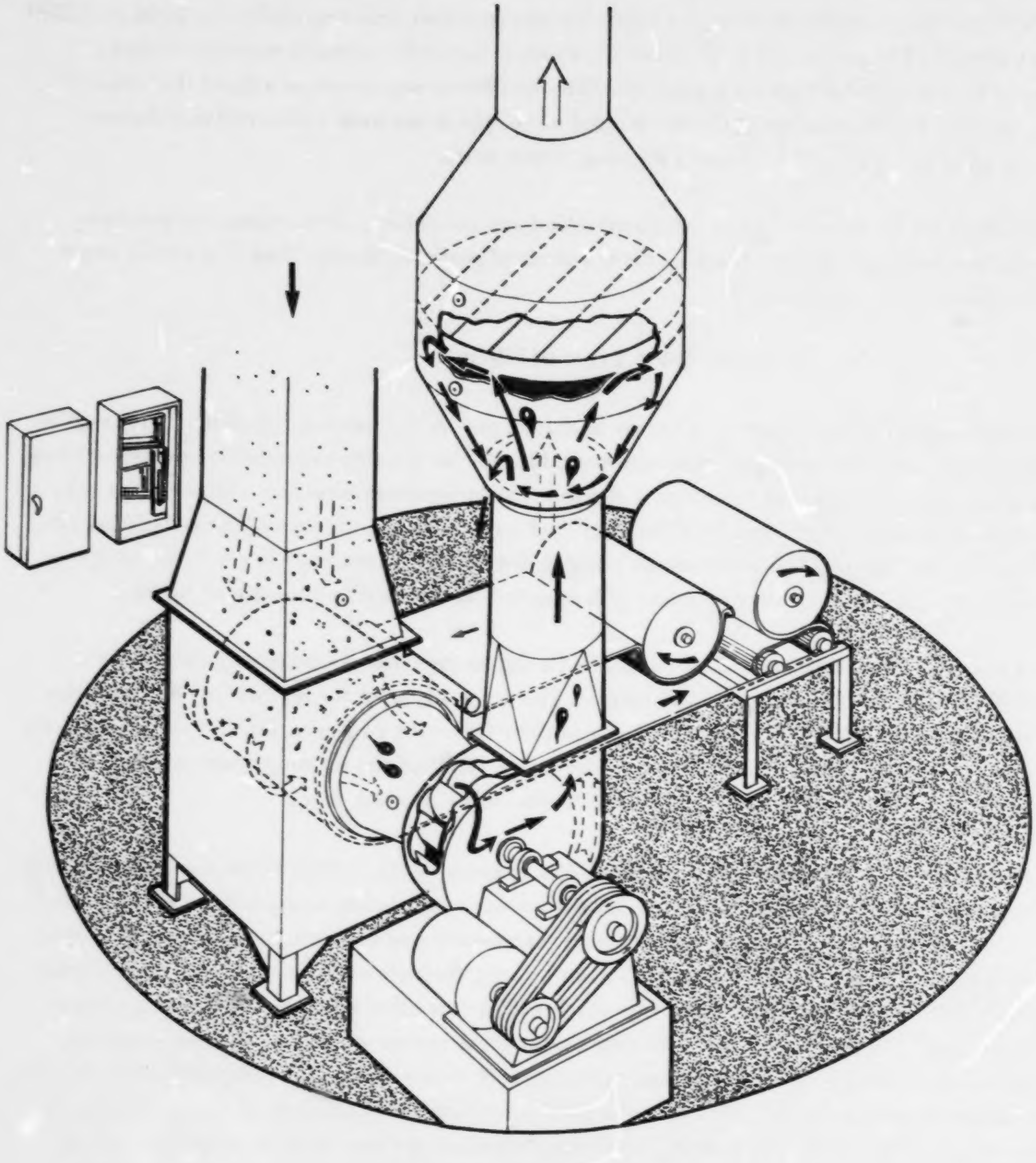


FIGURE 9-11

HIGH VELOCITY FILTER SYSTEM

Source: Johns-Manville Corporation

9.2.2.3 Electrostatic Precipitators

Electrostatic precipitators can be used for collection of particulates down to 0.1 microns with 95 to 99+% efficiency (3), (23), (24). Exhaust air is first passed through an ionizing grid, where the dust and droplets receive a positive change, which subsequently causes them to be attracted to negatively charged collection plates. Freely flowing oils will coalesce on these plates and run off into a collection device., while dust, tars, etc. will remain on the plates, from which they must be removed by periodic washing or rapping. Since excessive buildup on the collection plates insulates them, causing loss in collection efficiency, it is generally best to remove large easily removed particles prior to electrostatic precipitation. Water droplets should also be removed, as they can cause excessive arcing between the charged plates and damage. However, specially designed electrostatic precipitators are presently being used to collect acid mists (9), (25).

Electrostatic precipitators cannot collect vapors, and they will not therefore remove odorants from the exhaust, unless these odorants are carried by other liquid or solid contaminants. They are not recommended for use with explosive vapors or highly flammable liquids, as they are subject to occasional arcing even when operated properly. For collection of oil mists, arcing has not been found to be a problem. Some systems provide automatic power cutoff in event of arcing, with power restored when the arcing ceases.

However, precipitators can be damaged by stack fires that start in other places. Spark arrestors and quick acting bypass dampers are available. Some systems can also be made to begin their wash cycles or to flood themselves with steam or carbon dioxide gas in event of fire. Breakage of ionizing wires due to excessive arcing and power pack failures are the most common electronic problems that can occur.

Most maintenance problems are associated with dust and sludge buildup. Automatic cleaning is generally provided, either with steam or with a detergent wash. Generally the systems are shut down once a week for a 2 to 4 hour cleaning cycle, which can be either automatic or manually initiated. Manually initiated cleaning is recommended, since it forces regular observation of the equipment, which may otherwise be overlooked, because it is generally located on the plant roof and is not directly associated with production.

Installed costs of systems that include electrostatic precipitation vary widely with the complexity of the abatement problem. For cleanup of exhausts containing oil mists from texturizers, where no pre-cooling is necessary, installed costs of the entire electrostatic precipitation system range from $2.00 to $3.25 per CFM (1974 prices). For cleanup of tenter frame exhausts, where cooling of the air is necessary to condense the oil prior to precipitation, installed costs of the total system range from $2.22 to $4.00 and up per CFM (1974 prices). Systems which incorporate heat recovery devices or which require complex cleaning can cost as much as $12.00 per CFM capacity. If additional capacity or efficiency may be needed in the future, space can be provided for addition of future precipitation cells in series or parallel with the first.

Operating costs are extremely low because of the low pressure drops required (1/4 to 1/2 inches of water) and the small consumption of electric power. A 1000 CFM system typically requires a 5 HP blower and one kilowatt of electric power to energize the precipitator. At $0.02 per KWH, the electricity cost would be about $0.10 per hour.

Detailed design and application criteria for electrostatic precipitators are given in the EPA Air Pollution Manual (8), pp. 136 to 166, and in Perry's Chemical Engineers' Handbook (9), 5th ed., pp. 20-103 to 20-115.

9.2.2.4 Adsorption

Gaseous pollutants can be removed from exhaust air by selective adsorption onto solids. Adsorption of gases onto solids and desorption from them are complex physical and chemical phenomena that are not entirely understood. In general, substances adsorb more readily (and are consequently more difficult to desorb) the higher their boiling points. Adsorption also takes place more readily in small diameter pores than on open surfaces. In addition, the solids themselves will preferentially adsorb certain compounds. Activated carbon adsorbs all organics in preference to water, while other common adsorbents such as silica gels, synthetic zeolites, and metallic oxides are more selective in the substances they will adsorb and, generally, will adsorb water in preference to organics (11), (26).

The present discussion is related to the general case, which is primarily physical adsorption. Chemical adsorption is a special case, where chemical bonding is added to the physical mechanism, creating complex relationships in adsorption, desorption and deactivation, which do not lend themselves readily to general treatment.

Adsorption is a competitive dynamic phenomenon, so that more strongly adsorbed substances, such as oil vapors, will gradually displace less strongly adsorbed substances such as low molecular weight organic solvents. At any temperature, there is an equilibrium between the molecules on the solid surface and those in the gas phase. Adsorbed substances can, therefore, be evaporated from the surface into a vacuum or into an inert carrier gas, or they can be boiled from the surface by heat. Common drycleaning solvents, for example, can be flushed from activated carbon with low pressure steam, but spinning oils, plasticiers, etc., that generally comprise oil mists can only be driven off with steam superheated to 650° F (8).

Activated charcoal is best employed for removal of organic substances with a molecular weight above 45 or a boiling point above 32° F (11); however, it is not feasible to use it for removal of high boiling oils, as these deactivate the charcoal by almost irreversible adsorption as mentioned above. For compounds containing chlorine, fluorine or sulfur, carbon adsorption is often the only economically feasible means of removal, since incineration produces $HC1$, HF or SO_2 respectively. If the system is sized and operating properly, it is possible to remove virtually all of the pollutants, reducing exhaust concentration to less than 1 ppm. Typical solvents recovered by carbon adsorption include hexane, heptane, alcohol, carbon tetrachloride, freon, ethylene dichloride, chloroform, toluene, acetone, methylene chloride, perchloroethylene, trichloroethylene and 1, 1, 1, trichloroethane (11).

All catalysts lose activity with time, and activated carbon is no exception. Deactivation of the carbon beds has several causes:

1. Loss of surface area due to mechanical abrasions, sintering and plugging of the pores. Since the adsorption of hydrocarbons on activated charcoal is primarily a physical process, it takes place according to the classical Brunauer Emmett & Teller isotherm, whereby a disproportionate amount is adsorbed in the small diameter pores, which are most easily plugged or sintered shut.

2. Adsorption of high boiling oils, which are not removed by low pressure steam stripping. Physical adsorption is most easy and desorption most difficult for substances with higher boiling points such as oils. These can gradually render the carbon surface unavailable for solvent adsorption.

3. Poisoning of the catalyst. Substances like tri-isotoluene, which is used in urethane manufacture, and probably also cyclohexenone, can irreversibly deactivate activated charcoal catalysts.

4. Channelling and bypassing in the bed, due to settling.

The deactivation process can be substantially slowed if proper precautions are taken to avoid deactivation conditions. A pre-filter, regularly changed, can eliminate most entrained oils and lint. Catalyst poisons can be largely removed by inclusion of a small sacrificial charcoal bed before the main bed. One manufacturer claims that properly maintained carbon beds will last 5 to 15 years (probably an optimistic figure), but recommends laboratory checks of the carbon activity every 3 months. The simplest check on activity is with the stack analyzer, since a properly sized working system will reduce hydrocarbon concentrations in the exhaust air to 1 to 3 ppm.

When chlorinated solvents such as perchloroethylene, trichloroethylene, methylene chloride, and especially 1, 1, 1, trichloroethane are steam stripped, hydrochloric acid is present in the bed. Since the activated carbon has catalytic properties, corrosion problems can be severe, and 304 and 316 stainless steel is not acceptable for carbon beds to recover chlorinated solvents. Most carbon adsorption systems are therefore lined with baked phenolic. A carbon bed for methylene chloride recovery with a baked phenolic coating can last 20 years under these conditions, while a bed of 304 stainless steel would last only 3 months.

Typically, activated carbon beds are arranged in parallel for continuous operation. While one bed is being stripped of adsorption substances, the other beds are adsorbing impurities from the exhaust. In some non-continuous operations a single bed can be used if it has sufficient capacity to adsorb all the gaseous pollutants emitted from the process, and if it can be regenerated in time to be used the next time the process is performed. Detailed design and application criteria for carbon adsorption systems are given in the EPA Air Pollution Manual (8), pp. 189-199.

9.2.3 Scrubbers

Scrubbers are gas-liquid contacting devices, in which liquid, solid, or gaseous components carried in the gas stream are removed by adsorption into and by adhesion to the liquid. The liquid employed may be water, a water solution, or slurry of chemicals that will react with the substances to be collected, or it may be an organic liquid. Non-aqueous scrubbing is used principally for collection of organic vapors that are only slightly soluble in water. Scrubbers have the disadvantage that the pollutants are collected in a liquid, so that an air pollution problem may be solved by creation of a water pollution problem. However, if existing water effluent treatment facilities have the capacity to handle the additional load produced by the scrubbers, or if the pollutants can be easily removed from the water by filtration, oil skimming, etc., scrubbing is a feasible method of pollution abatement that has the advantage that its technology is relatively well developed.

9.2.3.1 Gas-Liquid Scrubbing

Removal of vapors from an exhaust stream can be accomplished most effectively by packed towers or tray towers. Packed towers are hollow cylindrical vertical towers, where the liquid is introduced as a spray at the top and flows downward through the packing, which may consist of marbles, ceramic saddles, raschig rings, crushed glass, etc. The packing serves to disperse the liquid into a high surface area film to facilitate contact with the gas, which travels upward through the tower. Wetted fiber or wire mesh filters can also serve as packed towers to a certain extent. In plate towers, the packing is replaced by perforated, horizontal plates. The liquid flows across each plate as it descends the column, while the gas bubbles up through the holes in the plate.

Packed columns have the advantage of low liquid holdup in the column. Corrosive materials, such as acids, can be easily handled, because the packing can be made of inert material. Degree of liquid agitation is low, allowing liquids that tend to foam to be more easily handled. Unless packed columns are greater than 2 ft. in diameter, packings must be of expensive alloys, packed columns are generally cheaper than plate columns (9).

Plate columns exhibit broader operating ranges than packed columns, and they can handle higher liquid rates more efficiently than packed columns. They are easier to clean if there are solids present in the system. Cooling coils can be incorporated into them more easily than into packed columns. They are not subject to damage by thermal shock or packing breakage during installation as are packed columns and they are completely wetted at low flow rates, whereas packed columns can develop dry spots, resulting in reduced efficiency (9).

Both packed and plate columns can be plugged by solids buildup and therefore require prefilters if lint or high concentrations of dust are present in the exhaust. They can both pre-cool the exhaust and remove vapors, though care must be exercised in the case of packed columns, as they can develop hot dry spots at the bottom at low water flow rates. They are not effective in removing sub-micron particulates, such as oil mists, which require higher energy scrubbing. When properly operated, liquid entrainment is not a serious problem.

Detailed design and application criteria for plate and packed columns are given in the EPA Air Pollution Engineering Manual (8) 2nd ed., pp. 207-229, and in Perry's Chemical Engineers' Handbook, 5th ed., (9) Section 14 and 18.

Spray towers consist of open chambers in which the scrubbing liquid is sprayed downward from the top, while the gas rises countercurrently. Liquid droplets should be 500 to 1000 microns in diameter for optimum results (8). Smaller droplets require a higher pressure drop in the nozzles and can be entrained by the gas. In cyclone spray chambers, of the type shown in Figure 9-12, liquid entrainment is less of a problem, since the liquid is thrown to the walls by centrifugal force, exactly as in a cyclone dust collector (see Section 9.2.1). However for both types of spray chambers, mass transfer is limited to one, or at the most two theoretical stages. Therefore spray chambers can be used as gas absorbers only in cases where the gas is readily soluble in the liquid. They are generally used to pre-cool and humidify an exhaust stream prior to cleanup. Lint, fly, and other particles down to 10 microns can also be removed by spray towers. Cyclone spray scrubbers are capable of removing particles as small as 2 microns in diameter (9).

Another method of scrubbing a gas is to bubble it through a tank of absorbing liquid, or through several tanks in series. The gas is dispersed into fine bubbles, either with a sparger or with a mechanical agitator, to obtain the maximum possible surface area for mass transfer. Because of the agitation of the gas bubbles, the liquid can be assumed well mixed. Mass transfer is therefore limited to one theoretical stage, but if the liquid contains a chemical that can destroy the absorbed pollutant, higher levels of efficiency can be achieved.

Design criteria for bubble type absorbers have been well developed only for the oxygen-water system, which finds extensive application in aeration lagoons. Other gas-liquid systems are generally correlated with reference to it. The principal parameters are gas phase mass transfer resistance, interfacial area (interfacial resistance) liquid phase mass transfer resistance and hold-up of the gas phase. Of these, gas phase mass transfer resistance is generally low and can be disregarded.

Interfacial area depends on the fractional gas holdup, the liquid volume, and the Sauter bubble diameter, which is defined as that bubble diameter that will give the observed average bubble surface to volume ratio. The relationship for spherical bubbles is:

$$a = \frac{6 \epsilon V_l}{D_b} \qquad \text{(9.7) (Reference 2, p 18-78 Adapted)}$$

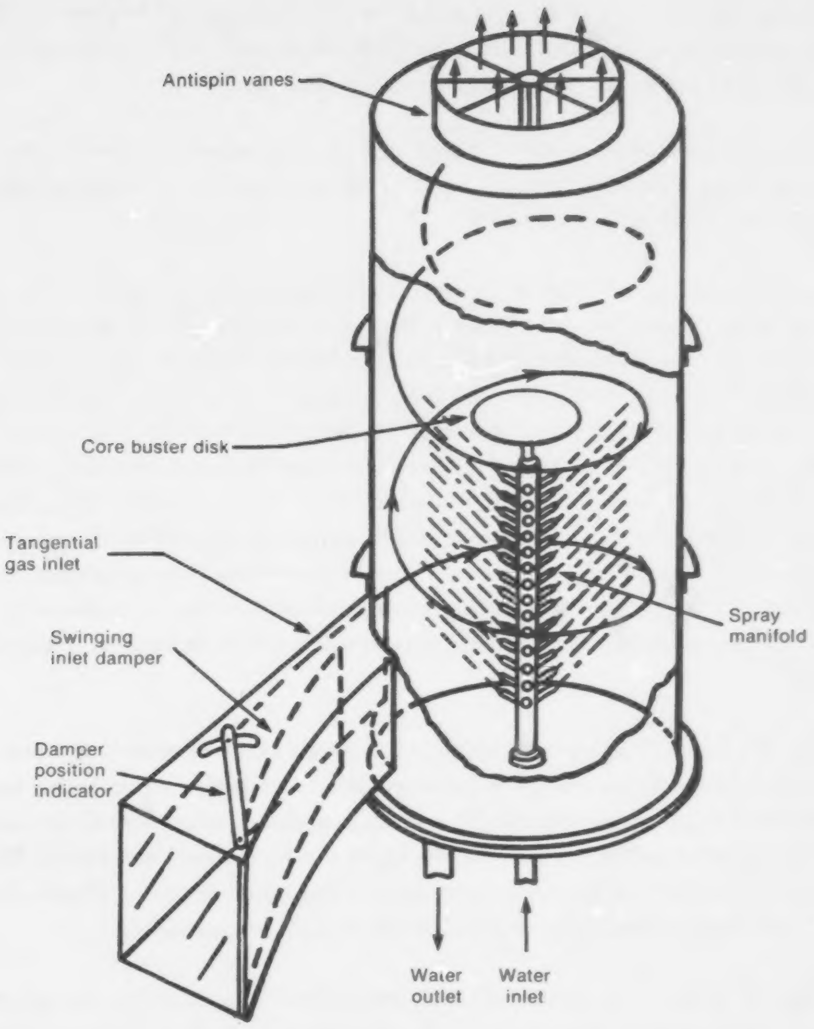

Antispin vanes
Core buster disk
Tangential gas inlet
Swinging inlet damper
Damper position indicator
Spray manifold
Water outlet
Water inlet

FIGURE 9-12

CYCLONE SPRAY CHAMBER

Except at gas velocities below 0.2 ft/sec, where sparge design has an influence, bubble size and fractional gas holdup depend chiefly on the degree of agitation and the properties of the gas and liquid.

The interfacial area increases with increased mixing horsepower and gas velocity and decreases as the surface tension increases.

Interfacial effects are complex and difficult to predict in advance. Impurities concentrating at the interface can cause variations in surface tension which can increase or decrease interfacial turbulence, depending on the system. Smaller bubbles can be produced by reduction in surface tension, by surfactant imparted electrical charges that hinder bubble coalescence, or by large concentration gradients and heat effects that cause bubble break-up. In addition, impurities can concentrate at the interface, adding an interfacial resistance to mass transfer.

Liquid phase resistance to mass transfer is dependent principally on liquid phase viscosity, density, and diffusivity, which are difficult to alter at will. However, the driving force for transfer into the liquid phase can be increased by addition of a chemical to the liquid that will complex or destroy the dissolved vapor. Liquids in which the vapor is readily soluble should also be selected in preference to those in which it is sparingly soluble.

Gas holdup time should be maximized to provide adequate time for mass transfer to take place. The relationships are complex and empirical but, generally, increased agitation increases, and increased gas throughout decreases gas holdup time.

Greater detail is presented in Perry's Chemical Engineers' Handbook, (9), 5th edition, pp. 18-70 to 18-81, from which this discussion has been abridged. Bubble tank absorbers are useful chiefly as intermittent duty devices to remove vapors from the air being vented from a liquid storage tank during filling. They have the advantage that they are cheap, and easy to design, install, operate and upgrade if necessary.

9.2.3.2 Scrubbing for Particulate Removal

9.2.3.2a Inertial Impaction Scrubbers

The primary mechanism for removal of particulates from a gas by scrubbing is inertial impaction of the droplet and the pollutant particle. Figure 9-13 shows how this is accomplished. Particles following the gas streamlines approach a collecting surface with relative velocity V_O. As the gas streamlines bend around the collecting surface, the particles are unable to follow them because of their inertia. Those within the flow cross section of width X, will be intercepted by the collector. The collection target efficiency N_T, is defined as the ratio of the interception area of a collector to its cross sectional area. In the case of a spherical droplet of diameter D_d

$$N_T = X^2/D_d^2 \qquad (9.8)$$

The target efficiency is related to a dimensionless separation number N_{sf} according to the graph in Figure 9-14. The separation number is given by:

$$N_{sf} = \frac{K_m \rho_p D_p^2 V_o}{18 \mu_g D_d} \qquad (9.9)$$

Therefore, particulate collection efficiency of a conventional scrubber is increased by increasing the particle-droplet relative velocity and by decreasing the droplet diameter. Since either of these methods requires an increase in applied power, collection efficiency of all scrubbers increases as the energy input to them is increased. As a rough approximation, all scrubbers operating at the same horsepower have the same efficiency for collection of particles of a given size. However in practice, particulate losses have been observed to vary by more than a factor of three from one scrubber to another at the same pressure drop.

Figure 9-15 shows the minimum particle size at which various types of conventional scrubbers have an 80% collection efficiency. As can be seen, scrubbers capable of operating at higher pressure drops can collect particles of smaller diameter. Knowledge of pollutant particle size distribution is therefore essential to proper scrubber specification. If the actual particle size distribution is not known, or if it may be subject to change, a scrubber of variable efficiency should be considered, such as Venturi scrubber with throat of variable cross section.

If gas absorption is to be carried out concurrently with particulate removal, a scrubber with long countercurrent gas-liquid contact time, such as a packed tower, should be considered. Packed towers as vapor absorbers are discussed in section 9.2.3.1.

If the solids loading in the exhaust exceeds about 20 grains per cubic foot, plugging can be a problem. Open scrubbers, such as spray towers or baffle towers, are least susceptible to plugging and are often used as pre-cleaners in preference to easily plugged scrubbers.

Other common problems associated with inappropriate design include re-entrainment of scrubber droplets, stack condensate blow-out, and freezing. Re-entrainment is generally prevented by use of a mist eliminator (see section 9.2.2.2) after the scrubber. Stack condensate fallout occurs when vapors condensing downstream of the scrubber adhere to the walls of the stack and collect some of the particles that escaped the scrubber. This buildup can blow out of the stack as a slurry if the stack velocity exceeds 20 ft/sec. Freezing in cold weather can be avoided by making provisions for complete drainage of water from all parts of the scrubber system.

A detailed schematic of an impingement scrubber illustrating the gas flow through the orifice is

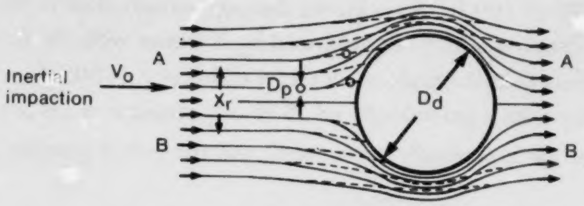


FIGURE 9-13

EFFICIENCY OF INERTIAL IMPACTION

Source: Reference 9

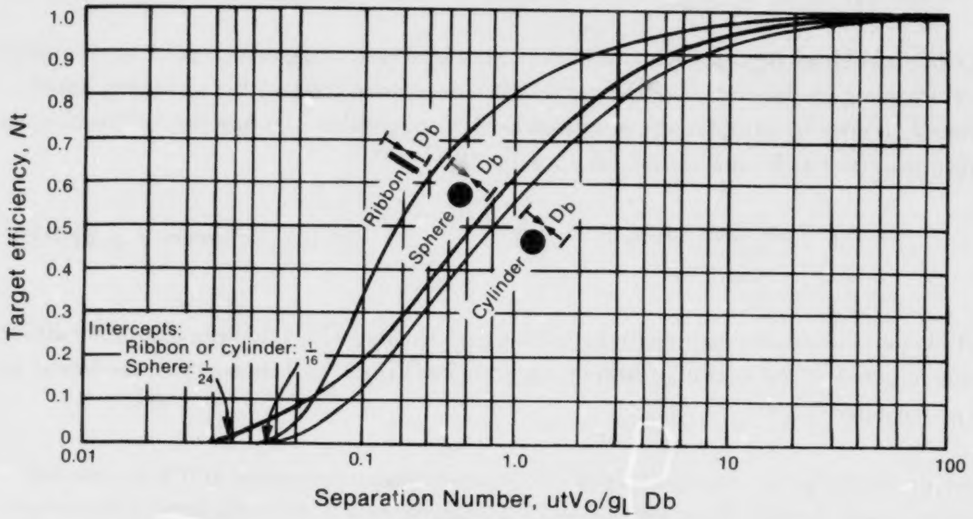


FIGURE 9-14

RELATION OF TARGET EFFICIENCY TO SEPARATION NUMBER

Source: Reference 9

	Pressure drop, in. water	Min. particle size, μ
Spray towers	0.5-1.5	10
Cyclone spray scrubbers	2-10	2-10
Impingement scrubbers	2-50	1-5
Packed- and fluidized-bed scrubbers	2-50	1-10
Orifice scrubbers	5-100	1
Venturi scrubbers	5-100	0.8
Fibrous-bed scrubbers	5-110	0.5

FIGURE 9-15

MINIMUM PARTICLE SIZE FOR VARIOUS TYPES OF SCRUBBERS

Source: Reference 9

shown in Figure 9-17. Gas at 75 to 100 ft/sec. is blown through modified sieve plates, where it contacts the liquid, forming droplets which are atomized by collision with the baffles located above each orifice. The droplets thus formed have a target efficiency of 80% for one micron particles of 2.7 specific gravity with a gas velocity of 75 ft/sec. Pressure drops are about 1.5 inches of water per plate. The gas is generally pre-wetted, and the coarse particles are removed with a spray tower scrubber.

Fluidized bed scrubbers, of the type shown in Figure 9-18, consist of sections containing low density spheres held between perforated plates. Scrubbing liquor flows downward, countercurrent to the gas. The violent motion of the spheres minimizes fouling. Pressure drop is 4 to 6 inches of water per stage.

With orifice scrubbers, high gas velocities are created by a restricting orifice prior to gas-liquid contact. Droplets are formed when the gas is blown over the surface of the scrubbing liquid. Equation 9.10 gives the droplet size produced by orifice scrubber as a function of liquid-to-gas ratio (gallons/1000 ACF) and superficial gas velocity:

$$D_d = \frac{16,050}{V_g} + 1.41 \ (L/G)^{1.5} \qquad \text{(9.10) (Reference 9, p 20-100)}$$

Collectible particle size decreases with increasing gas velocity, with velocities exceeding 400 ft/sec being required for collection of submicron particles. Figure 9-18 shows three models of orifice type scrubber.

Venturi scrubbers operate by injection of a water spray into a gas stream as it is accelerated through a Venturi nozzle. Equations 9.9 and 9.10 can be used to estimate their performance. Generally a pressure drop of 40 to 70 inches of water is required to remove the submicron droplets of a textile oil mist (23). Figure 9-19 shows a typical Venturi scrubber, with a cyclone following to collect the water mist created by the Venturi.

Water jet scrubbers of the type shown in Figure 9-20 function as aspirators, with the high velocity water stream pumping the gas. Pressure increases of up to 8 inches of water can be achieved in the gas, with 50 to 100 gallons per 1000 cubic feet of air required to create a one inch pressure increase. Relative liquid gas velocity is low, resulting in low collection efficiencies for particles of less than 5 microns diameter. Water jet scrubbers require a collection device following the scrubber for air-water separation.

One patented system, shown in Figure 9-21, employs the waste heat of the exhaust gases to power the water jet. Exhaust gases at 800 to 4000° F are heat exchanged with 0.8 to 1.0 lb/lb of scrubbing water. Water (3 gallons/1000 ACF) at 400° is sprayed from the nozzle with 15% vaporization, to give 10 micron droplets travelling at 1000 ft/sec. in a gas of 100 ft/sec. velocity. Removal efficiency is reported at 99.6% for particles of which 85% are smaller than 0.1 micron diameter (27), (28).

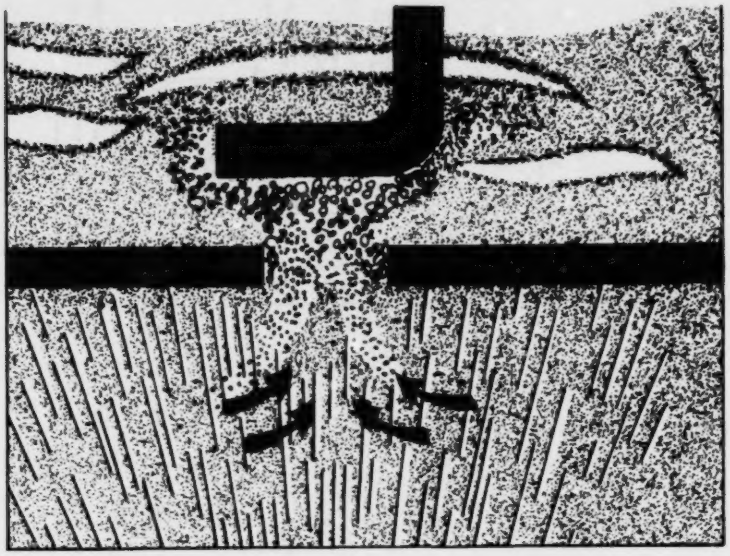


FIGURE 9-16

ORIFICE OF AN IMPINGEMENT SCRUBBER

Source: Sly Manufacturing Company

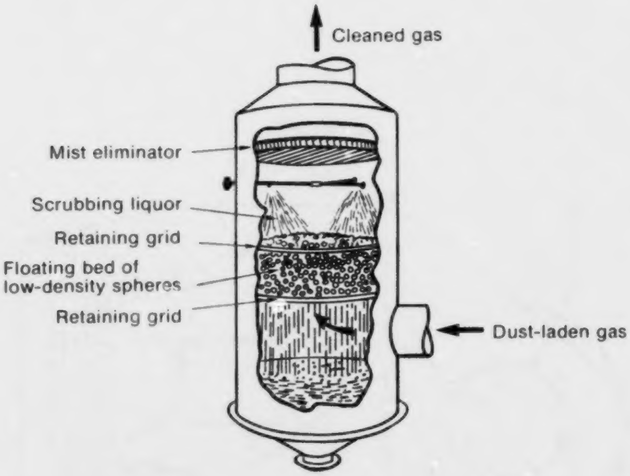

Cleaned gas
Mist eliminator
Scrubbing liquor
Retaining grid
Floating bed of low-density spheres
Retaining grid
Dust-laden gas

FIGURE 9-17

FLUIDIZED-BED SCRUBBER

Source: UOP, Air Correction Division

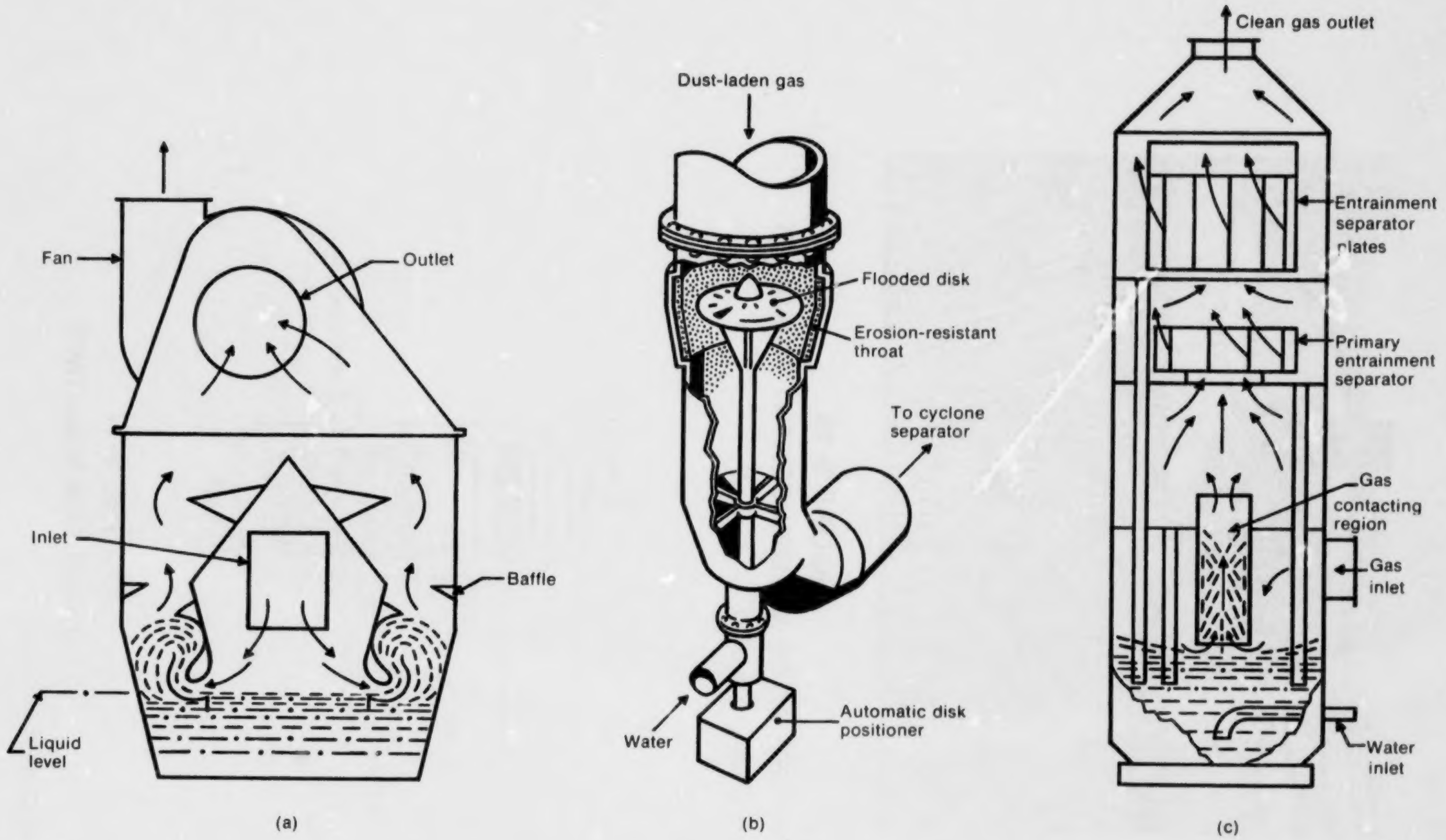

Fan
Outlet
Inlet
Baffle
Liquid level
(a)
Dust-laden gas
Flooded disk
Erosion-resistant throat
To cyclone separator
Water
Automatic disk positioner
(b)
Clean gas outlet
Entrainment separator plates
Primary entrainment separator
Gas contacting region
Gas inlet
Water inlet
(c)

FIGURE 9-18
ORIFICE SCRUBBERS

Sources: (a) American Air Filter Company
(b) Research-Cottrell, Inc.
(c) Blaw-Knox Company

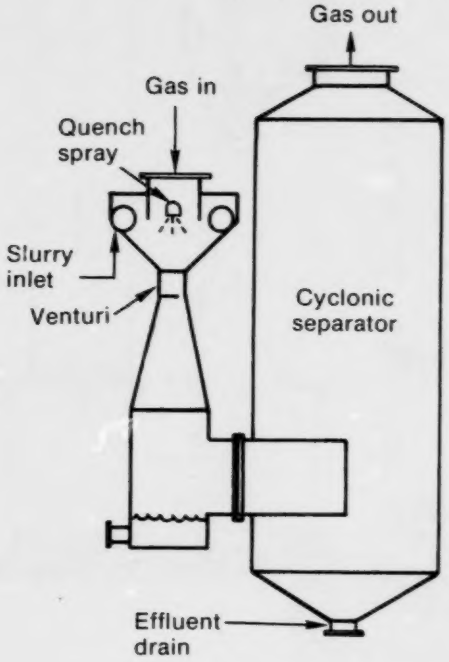

Gas out
Gas in
Quench spray
Slurry inlet
Venturi
Cyclonic separator
Effluent drain

FIGURE 9-19
VENTURI SCRUBBER

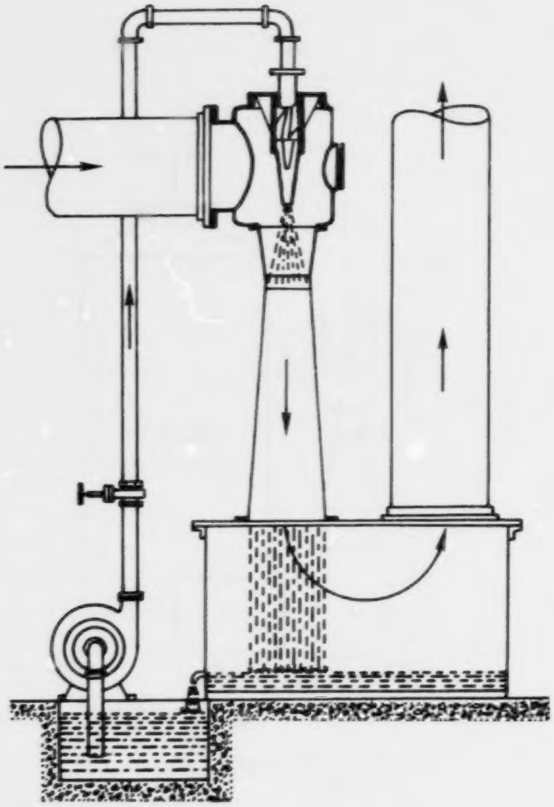


FIGURE 9-20
WATER-JET SCRUBBER

Source: Schutte and Koerting Company

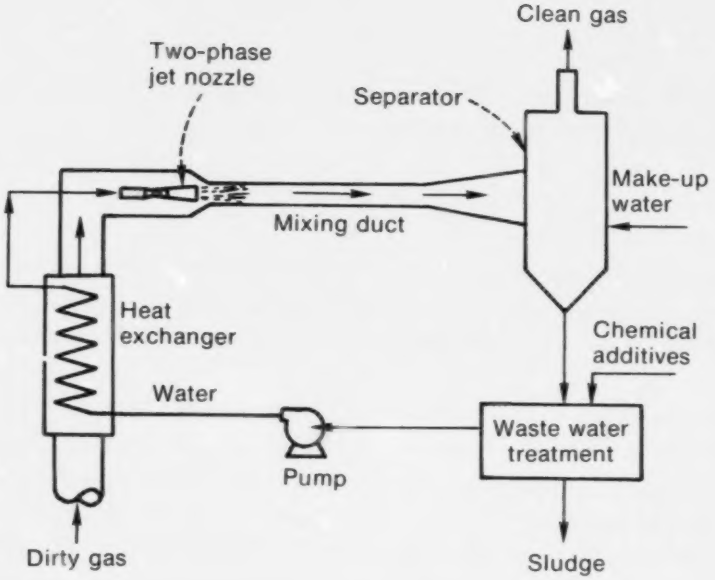

Clean gas
Two-phase jet nozzle
Separator
Make-up water
Mixing duct
Heat exchanger
Chemical additives
Water
Waste water treatment
Pump
Dirty gas
Sludge

FIGURE 9-21

TWO-PHASE FLASHING WATER JET SCRUBBER

Source: ADTEC, Inc.

In mechanical scrubbers, jets of water are sprayed at rotating blades which atomize the water droplets and accelerate them. A cyclone is usually provided to remove the dirty liquid. Dust loading is usually limited to 0.5 grains per cubic foot to minimize build-up of deposit on the rotor. Figure 9-22 shows a typical mechanical scrubber. Collection efficiency varies with configuration and blade speed. The Theisen Disintegrator, a common mechanical scrubber, can collect particles down to one micron with a power consumption of 10 HP/1000 CFM.

Fiber bed scrubbers are combination filters/scrubbers in which the pollutant particles are collected by impaction on a wetted fiber matrix. The matrix is generally kept continuously clean, either by a liquid wash or by deliberate re-entrainment of the liquid droplets and subsequent collection. Fiber bed scrubbers function essentially as high velocity air filters, which are discussed in Section 9.2.2.2c.

Additional information on inertial impaction scrubbers is given in Perry's Chemical Engineers' Handbook, 5th ed., pp. 20-94 to 20-104 (9).

9.2.3.2b Other Particle Scrubbers

Two other collection mechanisms can be employed to obtain greater collection efficiency at a lower expenditure of energy than can be obtained with a scrubber operating purely on the principle of inertial impaction. These are condensation and electrostatic attraction.

Figure 9-23 shows a scrubber operating on the flux force condensation principle, which is currently being demonstrated by Air Pollution Technology, Inc., of San Diego, California (28). Steam is injected into the exhaust stream and then cooled. Pollutant particles serve as condensation nuclei, thereby increasing in size and becoming more easily collectable by impaction. An additional phenomenon known as Stegan flow (9), causes particles to be attracted to the condensing droplets, facilitating agglomeration. A 1000 CFM unit has successfully been operated, and a 5000 to 10,000 CFM unit is being started up on a secondary metals recovery furnace.

Electrostatic attraction is combined with wet scrubbing for fine particulate removal at low pressure drop in three recently developed systems (29), (30), (31). The first, called a charged droplet scrubber, is shown in Figure 9-24. It collects pollutant particles with a spray of electrostatically atomized charged water droplets that are accelerated toward a collection plate. The pollutants are collected by the droplets by a combination of impingement and the electrostatic attraction of the dipoles induced in them in the presence of the charged droplets, called image force attraction. The scrubber has been used successfully in the Japanese steel and pulp and paper industries, collecting one micron particles with 99% efficiency, and submicron particles with 90 to 96% efficiency at a water consumption of one gallon/1000 ACF. It is offered by TRW Environmental Products Division, Redondo Beach, California.

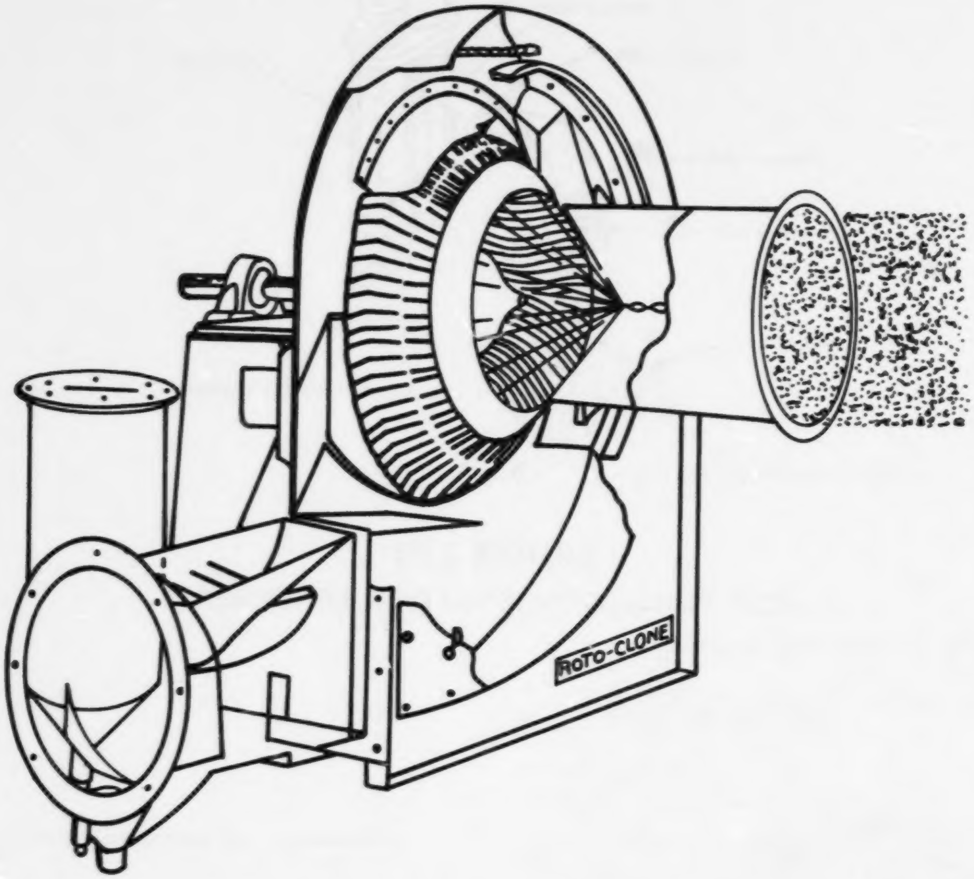


FIGURE 9-22
MECHANICAL SCRUBBER

Source: American Air Filter

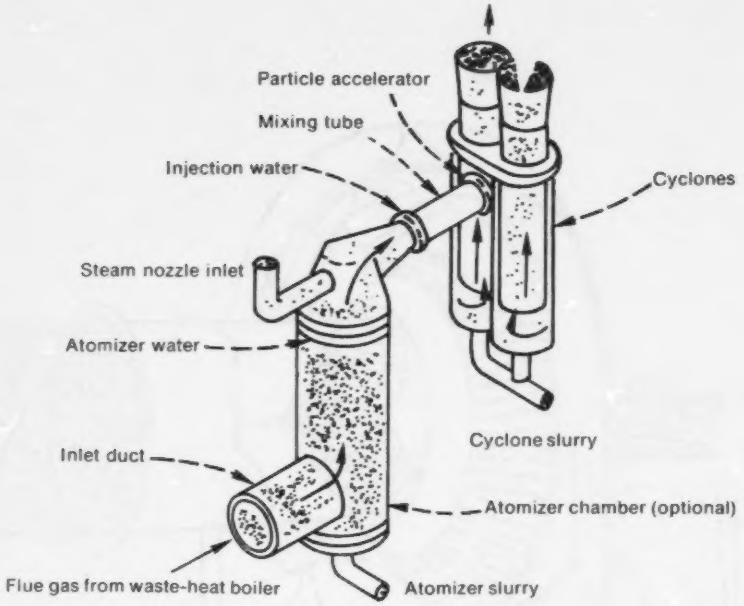

Particle accelerator
Mixing tube
Injection water
Cyclones
Steam nozzle inlet
Atomizer water
Cyclone slurry
Inlet duct
Atomizer chamber (optional)
Flue gas from waste-heat boiler
Atomizer slurry

FIGURE 9-23

FLUX FORCE CONDENSATION SCRUBBER

Source: Air Pollution Technology, Inc.

	Estimated Performances			
	Venturi Scrubber[4]	Bag House[2]	Electrostatic Precipitator[3]	CDS[1]
Power[5] watts (ft^3/min)	4.0-12.0	1.0-1.3	0.3-0.8	0.3-0.5
Residence time[6], min	0.01	0.09-0.14	0.12-0.20	0.03-0.04
Collecting area/flowrate, $ft^2/(ft^3/min)$	not applicable	0.2-0.5	0.2-0.6	0.06-0.20
Pressure drop, in. H_2O	20.0-60.0	4.0-6.0	0.2-0.5	0.5-0.7

1—For 3 to 4-in collector spacing
2—At air-to-cloth ratios or 3 and 5, pulse air cleaned
3—For 2-3 and 3-5 field sectionalization
4—For 20-60 in. H_2O pressure drop
5—Includes process gas fan, power supplies, and auxiliaries
6—Includes demisters, hoppers, gas distribution, and collecting sections

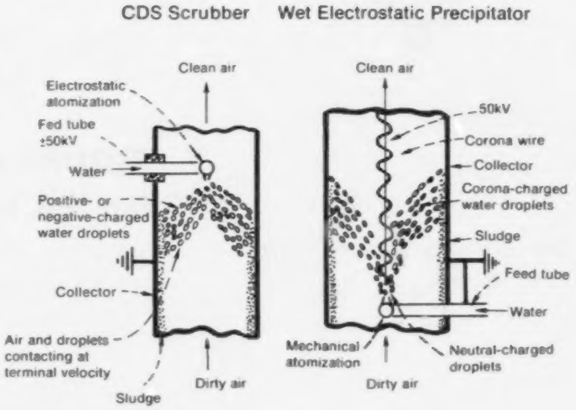

CDS Scrubber
Wet Electrostatic Precipitator
Clean air
Electrostatic atomization
Fed tube ±50kV
Water
Positive- or negative-charged water droplets
Collector
Air and droplets contacting at terminal velocity
Sludge
Dirty air
Clean air
50kV
Corona wire
Collector
Corona-charged water droplets
Sludge
Feed tube
Water
Mechanical atomization
Neutral-charged droplets
Dirty air

FIGURE 9-24

CHARGED DROPLET SCRUBBER

Source: TRW, Environmental Products Division

The second is an ionizing wet scrubber (shown in Figure 9-25) offered by Ceilcote Company, Berea, Ohio. Contaminated gases are passed through an ionizing section into a crosscurrent packed bed scrubber, where the charged particles are collected on Tellerettes by a combination of impingement and image force attraction. Collection efficiencies are 70 to 95% for particles down to 0.05 micron, and greater efficiency can be achieved by putting multiple units in series. Power consumption is 0.2 to 0.4 KVA/1000 ACF, with a pressure drop of 1.5 to 2 inches of water.

The third device, shown in Figure 9-26, is offered by Air Pollution Systems, Inc. of Tukwila, Washington. Particles are ionized prior to collection in a conventional scrubber, which in this case was a low energy Venturi scrubber. An electrical energy input equivalent to one to two inches of water resulted in improvement of collection efficiency to the same extent obtainable by an increased pressure of 20 to 25 inches of water in a conventional scrubber. With water usage of 9 gal/1000 ACF and a pressure drop of 11 inches of water, 97% removal of 0.8 micron particles was obtained.The ionizing system could be installed prior to any conventional scrubbing system to increase efficiency.

9.3 Elimination of Oil and Acid Mists and Associated Pollutants

9.3.1 Design Considerations

When textile materials are subject to heat treatment above 200° F, some volatilization of oils, waxes, plasticizers, etc., that are present on or in the material occurs, as was described in Section 9.1. The mist is formed when the vapor laden air is cooled to 110 to 160° F, causing recondensation of these low vapor pressure organic compounds into droplets of a diameter range of 0.1 to 1 micron, with 75% of the droplets being less than 0.5 micron in diameter.

Because of the small size of the droplets, techniques applicable primarily to lint removal or gas adsorption, such as bag filters and low energy scrubbers of the spray or packed tower type are not effective.

Feasible abatement techniques include process modification, incineration, high energy scrubbing, or the use of electrostatic precipitators, high efficiency fiber mist eliminators, or high velocity air filters. Three things must be known for proper specification of a mist eliminator system. These are:

- Air volume to be processed
- Temperature of air to inlet to abatement system
- Approximate exhaust composition

Exhaust air volume, in CFM, can generally be obtained from the manufacturer of the process equipment for which emission control is necessary. Figures supplied by equipment manufacturers are generally conservative, resulting in some overdesign of the emission control system.

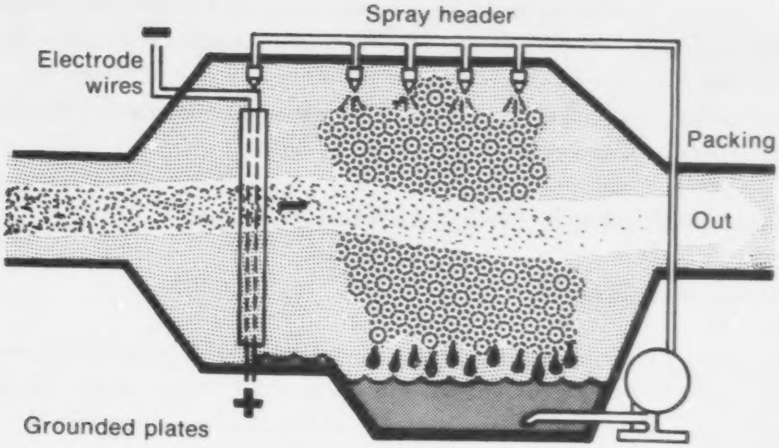

Spray header
Electrode wires
Packing
Out
Grounded plates

FIGURE 9-25
IONIZING WET SCRUBBER

Source: Ceilcote Company

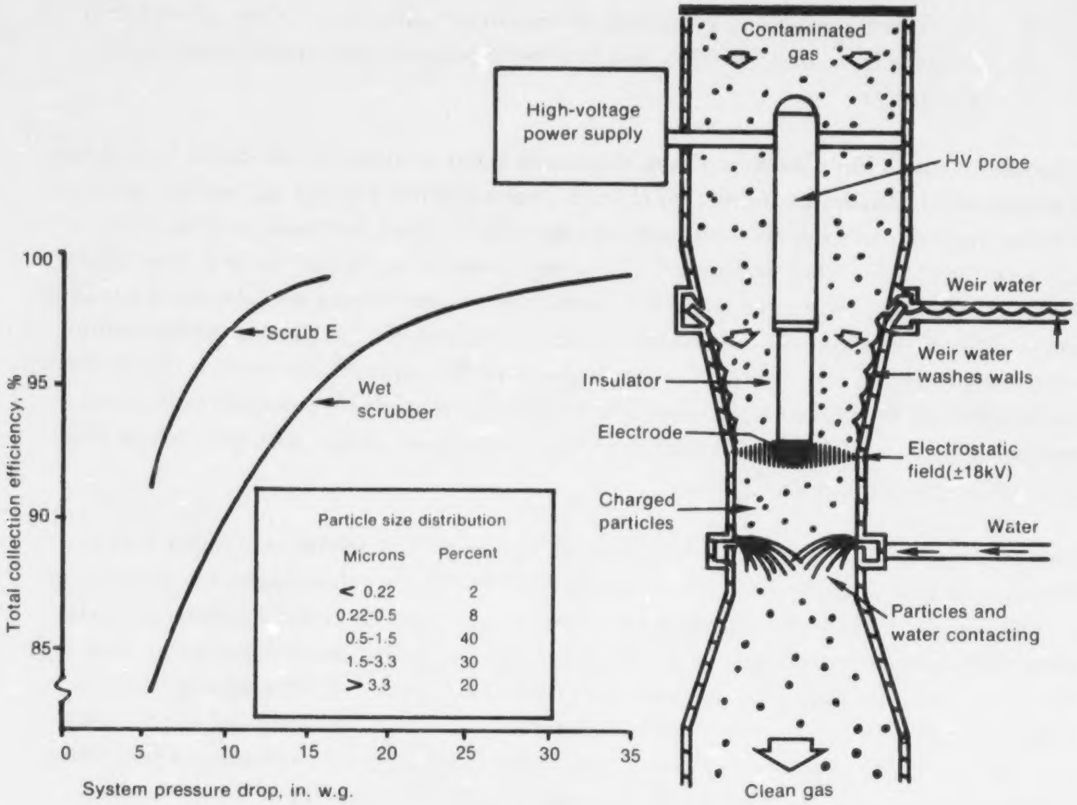

100
95
90
85
Total collection efficiency, %
Scrub E
Wet scrubber
Particle size distribution
Microns Percent
< 0.22 2
0.22-0.5 8
0.5-1.5 40
1.5-3.3 30
> 3.3 20
0
5
10
15
20
25
30
35
System pressure drop, in. w.g.
Contaminated gas
High-voltage power supply
HV probe
Weir water
Weir water washes walls
Insulator
Electrode
Electrostatic field(±18kV)
Charged particles
Water
Particles and water contacting
Clean gas

FIGURE 9-26

ELECTROSTATICALLY ENHANCED SCRUBBER SYSTEM

Source: Air Pollution Systems, Inc.

However, this overdesign constitutes a margin of safety which may subsequently allow for process changes that would tend to increase pollution problems, such as operating at higher temperatures or processing of fabrics containing larger quantities of volatilizable material.

In cases where the recommended CFM is not available from the process equipment manufacturer, or where abatement equipment is being added to existing processes, the minimum recommended CFM is limited by three factors: (2)

1. It must be sufficient to carry off all evaporated water in drying applications.

2. If the exhaust contains combustible material, the National Fire Protection Association recommends that exhaust air volume be high enough to assure that the flammable vapor concentration remains below 25% of the lower explosive limit in the worst case. 10,000 CFM of air (measured at 70° F) should be vented with each liquid gallon of evaporated oil or solvent (14).

3. Air velocities must be high enough to prevent recondensation of the oils and their dripping back onto the fabric and to prevent escape of the contaminants into the in-plant air.

Sometimes with multiple stack processes, abatement is not necessary on all stacks. In the case of tenters which also dry the fabric, for example, water is driven off first and can be exhausted without removal, while oils are driven off subsequently. On the other hand, volatile organics may be driven off the fabric at the start of a tentering operation, so that the first stack might need abatement, but the second might not. Knowledge of oven zoning may also allow the adoption of different emission control systems on different stacks, resulting in cost savings and/or greater efficiencies of removal (2). One disadvantage of this approach, however, is that it restricts the flexibility of the process equipment. When different materials are processed in the same equipment under a different operating condition, one cannot always anticipate which pollutant will be driven off at which stack.

Inlet air temperature to the pollution abatement equipment will determine whether further cooling is necessary, and whether it is economical to recover the exhaust heat. Composition of the pollutant is often the deciding factor in choice of a system. Mists that condense into relatively freely flowing liquids can easily be removed by electrostatic precipitators or by most high efficiency fiber eliminators, but mists that leave gummy or tarry deposits may require scrubbing, incineration or the use of renewable high velocity air filters. Quantity and condensation temperature of the pollutant determine the extent to which it would condense in a precooling system. Safety precautions required are determined by the flammability of the condensate, especially with electrostatic precipitators, mist eliminators and some heat recovery systems which are damaged by fire. Fires are especially common with tenter frame exhausts, since heating is often done with open flames. The exhaust gases are hot, and flammable liquids condense throughout the exhaust system. Stainless steel ductwork is recommended in places where fires can be a problem. Especially corrosive mists may require the treatment system to be constructed from special corrosive resistant materials.

An estimate of the chemical composition of the mist can be obtained from knowledge of the pre-history of the processed material, including the nature and amount of oils, plasticizers, solvents, dyes, carriers, resins, etc., applied to it, both previously in the mill and by its original manufacturers. Stack testing and knowledge of the emission character of other similar processes are also helpful. Stack testing is greatly simplified by foreknowledge of the pollutant chemicals likely to be present (2).

9.3.2 Emissions Preconditioning

Oil mist abatement consists of four steps, some of which may not be necessary, depending on the nature of the mist and on the abatement techniques chosen:

- Pre-removal of lint and dust
- Cooling of the contaminated air to condense the vapors to mist

- Removal of the mist from the air
- Collection and disposal of the contaminant

Removal of lint and dust is necessary with systems that would tend to become clogged with it. These include electrostatic precipitators, high efficiency fiber mist eliminators, and packed tower scrubbers. Some types of heat recovery equipment also require pre-filters (see Section 9.4). Lint and dust removal is not necessary prior to an incinerator, a venturi scrubber, or a high velocity air filter (though it would prolong its life). It is generally accomplished with a screen filter or a fabric filter placed in the exhaust line prior to cooling of the exhaust for oil condensation. For temperatures above 250° F, steel mesh filters are often used.

Cooling of the vapor laden exhaust air, generally down to 110 to 160° F, is necessary to effect recondensation of the organics prior to collection, unless removal is to be performed by an incinerator without recovery of the organics. With texturizer fumes, this is not necessary, as the air is already cool, but most other exhausts require some temperature reduction. This may be accomplished either by direct contact cooling or by heat recovery via a heat exchanger. Use of water scrubbing for pre-cooling reduces the problem of stack fires. Heat recovery equipment is generally more expensive than simple direct or indirect contact cooling equipment, but if some use can be found for the recovered heat, the additional expense can often be justified by reduced energy costs. Heat recovery from exhaust air is discussed in Section 9.4.

Precooling by direct contact water evaporation is accomplished by low-energy scrubbers. One manufacturer of electrostatic precipitators includes an optional pre-cooler consisting of a series of wetted filters through which the exhaust passes for lint removal and cooling prior to droplet precipitation.

Spray towers may serve as evaporative coolers as well as removing lint from the exhaust. These have a disadvantage, however, in that they can add water droplets to the mist, causing emulsions to coalesce in the mist-removing equipment. The effluent, therefore, can have a greater tendency to gum and solidify, and oil-water separation equipment is required after collection.

Packed towers combine the function of a pre-cooler and an absorber for odorous water soluble vapors. They can be plugged by lint and, therefore, require a pre-filter if the exhaust contains large amounts of lint. Chemicals can be added to the scrubbing liquid to facilitate pollutant vapor removal. Section 9.6 describes the use of packed tower scrubbers for odor removal.

Both as pre-coolers and as mist removers, scrubbers have the disadvantage that they are potential sources of water pollution. If water purification facilities already exist that can handle this additional source, then scrubbers are a relatively inexpensive form of emission pretreatment. Installation costs of various types of scrubbers are listed in Section 9.6.5. If space has been allowed at installation, the efficiency of a low-energy scrubber can be increased by addition of a venturi throat inlet (32).

9.3.3 Process Modifications

Since oil mists are caused by evaporation of oils from textile materials, their formation can be prevented by reduction of the oil content of the materials prior to heat treatment. Careful control of the application of spinning oils and fabric finishes to prevent excessive buildup on the fabric can reduce mist problems and simultaneously result in material savings. Scouring before tentering rather than after is possible in some cases, though in others tentering is required before scouring to impart dimensional stability to the fabric. To eliminate oil mist problems from tenter frames, input oil content must be reduced to below 0.5 weight percent (2).

Careful control of the heat input to the fabric can also prevent excessive oil evaporation as well as save energy. Dielectric drying and curing are feasible in some instances, either as total replacements for other forms of energy input or as supplementary energy inputs to effect precise energy control. Dielectric energy as an input source is inherently self-regulating since the rate at which any material absorbs dielectric energy is proportional to its dielectric constant. Water, with a high dielectric constant, absorbs energy rapidly and is dried from the fabric. When the fabric is dry, overheating does not occur, because the dielectric constant of the fibers is much lower. Dielectric heating can also be employed as a means of precise energy input in the curing of plastisols. While economics have previously not favored dielectric heating, the rising cost of energy and the increasing stringency of antipollution laws are making it increasingly attractive.

9.3.4 Electrostatic Precipitators

For mists that can be condensed into relatively freely flowing oils, electrostatic precipitators are the preferred abatement device because of their low operating and energy cost and their effective elimination of small diameter particles. The liquid effluent produced is relatively pure, presenting minimal disposal problems. For texturizing applications, no pre-cooling is necessary, but oil mists from tenter frames require pre-cooling and are also apt to be more gummy, waxy, and corrosive, because the higher temperatures involved in tentering cause evaporation of higher boiling point substances and partial oxidation of them to acids and gummy polymers.

Most maintenance problems are associated with dust and sludge buildup. A pre-filter is necessary to remove dust and lint. Dust can insulate the ionizing wires, causing loss of efficiency and arcing. Automatic cleaning is generally provided, either with steam or with a detergent wash. Water washes contaminate the effluent oil and may require a water separator for oil recovery. Generally the systems are shut down once a week for a 2 to 4 hour cleaning cycle. More trouble is experienced with condensates that can gum and solidify than with free flowing liquids, but ease of manual cleaning is always an important factor.

Gumming and solidification of the condensate can sometimes be avoided by raising the collection temperature above the gummy region. Since effluent mists of this type would be expected to have lower vapor pressures, they can often be collected at higher temperatures than can more freely flowing oils.

Arcing can also cause fires, but this has not generally been found to be a problem. However, stack fires can start in other places and can spread to the precipitator, which can be damaged by them. Spark arrestors and quick bypass dampers are available. Some systems can also be made to begin their wash cycles or to flood themselves with carbon dioxide gas in event of fire.

Unless designed for the application, electrostatic precipitators are not recommended where water droplets or condensation of water mists are expected, since water can cause arcing and short circuiting. In some applications, such as drying, where the exhaust air contains large amounts of water vapor, operating temperatures should be kept above 160° F to allow condensation of most of the oil without water condensation. Electrostatic precipitators designed for wet operation have found application in collecting sticky particulate.

Operation of electrostatic precipitators is discussed in greater detail in Section 9.2.2.3.

9.3.5 High Efficient Fiber Mist Eliminators

For removal of oil mists containing water, mist eliminators are preferred to electrostatic precipitators for reasons mentioned above. Such mists are produced during the drying, curing or tentering of fabrics containing significant amounts of moisture. High efficiency fiber mist eliminators can easily be installed after low energy scrubbers, which would be used for lint removal, pre-cooling, and abatement of odors due to gaseous contaminats. If a water spray can feasibly be incorporated in a mist eliminator, it will function as a packed tower scrubber, removing both mists and odors at once. Operating costs are higher than with an electrostatic precipitator because of the higher pressure drop required, which ranges from 5 to 15 inches of water. Mist eliminators are discussed in detail in Section 9.2.2.2.

9.3.6 Incineration

Incineration is the most proven and reliable method of emission destruction, since virtually everything in the exhaust is destroyed. Therefore it is worthy of consideration for destruction of oil mists, especially if they contain fibers, gums, and odorous vapors that would require additional treatment. Because of the high and rising cost of energy, incineration is generally also the most costly method of oil mist elimination. Care must be taken to prevent condensation of oil in the exhaust ducts leading to the incinerator, since this can create a fire hazard. Incineration is discussed in detail in Section 9.2.1. Heat recovery, which can reduce the operating costs of an incinerator, is discussed in Section 9.4.

9.3.7 Scrubbing

Because of the small diameters of oil mist droplets, they cannot be removed by low energy scrubbers, such as packed towers, spray towers or cyclone scrubbers, but removal efficiencies of up to 99% by weight can be obtained with Venturi scrubbers operating at pressure drops of 40 to 70 inches of water (23). Since the energy costs for operating scrubbers, even at this high pressure drop, are still lower than the energy costs of incineration, high energy scrubbers are generally preferred to incinerators for removal of extremely gummy mists, where electrostatic precipitators and high efficiency mist eliminators are generally inapplicable. They are also preferred to incinerators for removal of materials containing chlorine, fluorine, sulfur, phosphorous, etc., which would be incinerated to gaseous compounds that would still have to be removed from the exhaust by adsorption. In 1974, installed costs varied from $0.50 to $4.00 per CFM (11), with operating costs approaching those of fume incinerators.

Pre-filters and pre-coolers are not required, since Venturi scrubbers can also cool the exhaust and remove lint. If additional scrubbing is desired for odor removal (see Section 9.6), Venturi scrubbers can be followed by packed tower scrubbers.

If greater efficiency is required, the operating pressure drop of a Venturi can be increased if provisions have been made for this. Removal efficiency can also be increased by addition of surfactants to the water to promote emulsification, though this complicates the problems of liquid effluent disposal. Another type of Venturi consists of a tray of closely spaced cylindrical bars, which serve as slot orifices. Capacity can be decreased or pressure drop can be increased by blanking off sections of the tray. Additional trays can also be added, or the tray can be replaced by others with different bar spacings, permitting considerable flexibility of operations.

Because they require several hundred horsepower per 10,000 CFM (2), Venturi scrubbers are usually noisy. If they are not followed by mist eliminators, they produce water plumes which, while not illegal, can focus attention on effluent odors and become a source of complaint. They are subject to abrasion, especially at high lint loadings, and in the presence of corrosive substances (17).

The recovered pollutants are mixed with water, making reuse less feasible and disposal more cumbersome, and creating potential water pollution problems unless the effluent can be handled by existing water treatment facilities. In some cases, if the spray nozzles are properly designed, the contaminated water can be re-cycled. Solids must be removed, and if the scrubber is also to be used for absorption of odorous vapors, their buildup in the recycled water will limit the recycle ratio.

Additional information on the use of scrubbers for odor abatement is given in Section 9.6. Further details on the principles of scrubber operation and design criteria for scrubbers are given in Section 9.2.3.

9.3.8 High Velocity Air Filters

High velocity air filters are in-line fiber or mesh filters that remove fine mists from air streams by high velocity impaction of the droplets on the filter medium. They are best suited for removal of low droplet concentration aerosols of sticky particles, where re-entrainment of the droplet is less of a problem. Pre-filtration for lint removal is recommended to extend filter life, and pre-cooling is necessary to condense the mist. Post-filtration may also be necessary for reentrainment particles, though their size will be larger than those in the original mist. High velocity air filters are discussed in greater detail in Section 9.2.2.2.

9.3.9 Elimination of Acid Mists

The techniques applicable to oil mist elimination apply for the most part to elimination of acid mists as well, though special consideration must be given to the corrosive nature of the mists. Incineration is practical only if the mists contain no inorganic acids, such as H_2SO_4, HC1, HF, etc., or halogenated organic acids, such as trichloracetic acid. Mineral acids are unaffected by incineration, and halogenated organic acids are merely oxidized to the corresponding mineral acids. Specially designed electrostatic precipitators, generally lead lined, have long been used successfully in the chemical industry for acid mist elimination (9), (10), (25). High efficiency mist eliminators can also be used effectively if constructed of acid resistant material. Systems that employ high velocities, such as Venturi scrubbers and high velocity mist eliminators, are less suitable, especially in the presence of abrasive solid particles, since the acid corrosion resistance of many substances is due to the maintenance of a protective surface film, which is continually destroyed by abrasion. A detailed discussion of scrubber design for corrosion resistance is given in Section 9.2.3.

9.4 Heat Recovery Systems

Although the waste heat discharged to the atmosphere by textile processes is not yet considered to be itself a pollutant, heating and/or cooling of effluent air streams is often a necessary step in the pollution abatement process, especially in the removal of oil mists and in the recovery of solvents. With the exception of the texturizing processes, most processes that produce mists by thermal evaporation of oils, waxes, resins, etc. from textiles require pre-heated air and generate effluent air containing large amounts of recoverable heat. Pre-cooling of the exhaust air for condensation of the organics is necessary with mist eliminators, electrostatic precipitators, and high efficiency air filters, and it can be used with Venturi scrubbers if the economics of heat recovery warrant it. With incineration, on the other hand, the contaminated air must be heated, and heat can be recovered from the incinerator exhaust gases. In solvent recovery systems (see Section 9.5), precooling of the effluent air below 100° F is necessary prior to its introduction to the activated carbon beds.

Shortages and increased prices of fossil fuels have made the possibility of heat recovery from exhaust air an increasingly important consideration in specification of a treatment system. In choices between treatment systems of approximately equivalent performance, energy costs and savings can be the deciding factor.

9.4.1 Economics and Feasibility of Heat Recovery

The first consideration in the design of a heat recovery system should be the use to which the recovered heat can be put. Where possible, the most effective use of recovered heat is to recycle it to the process. Incinerator off gases can be used to preheat the contaminant laden input air. Exhausts from tenter frames, drying ovens, curing ovens, etc., can also be used to preheat the input air to these processes. However, it is not generally wise to use heat recovered from one process for a second unrelated process, since this greatly restricts mill operating flexibility. Moreover, even where recovered heat is reused in the same process, consideration must be given to the problems of startup, shutdown and unsteady state operation. For example, in the case of a tenter frame that recycles its heat, more input heat will be required at startup than at steady state to prime the system, while at shutdown, or when it is necessary to decrease the operating temperature, the recovered heat must be wasted or directed elsewhere.

If recovered heat cannot be recycled directly, heat recovery savings will be largest where the recovered heat can be used most continuously and over the longest possible period of time, as in the production of hot water or steam for which there is a continuous demand. If the recovered energy is used only for heating during the winter months, savings will be more limited, and alternative provisions will have to be made for disposal of this heat at other times.

The amount of heat recovery possible from oven exhausts can be calculated if the temperature and flow rate of the exhaust stream are known. Figure 9-27 shows the possible heat recovery in BTU/hr. which can be recovered from oven exhausts as a function of the exhaust air flow rate (CFM) for exhaust temperatures of 250, 300 and 350° F. It was assumed that the exhaust air was cooled to 150° F, since this temperature is easily achievable with ambient air or water as a coolant, even in the summer months. Figure 9-28 shows the annual dollar value of the recovered heat as a function of exhaust CFM for fuel costs of $1.00 to $4.00 per million BTU. It is assumed that the exhaust air is cooled from 300 to 150° F and that the heat recovery equipment operates 6,000 hrs./yr. In each case, it is necessary to correct these numbers for heat losses, both in the system for heat recovery and reuse and in the heat generation system, so that the number of BTU's the heat recovery system will actually deliver at the desired location can be compared to the cost of delivering the same number of BTU's to the same location by means of fuel consumption.

For example, if heat is recovered from one process for use at a distant location, heat losses in transmission and storage of the heated transfer fluid will reduce the number of BTU's actually delivered per BTU recovered from the exhaust. If a second heat exchanger is needed to recover heat from the transmission fluid, additional losses will be encountered there.

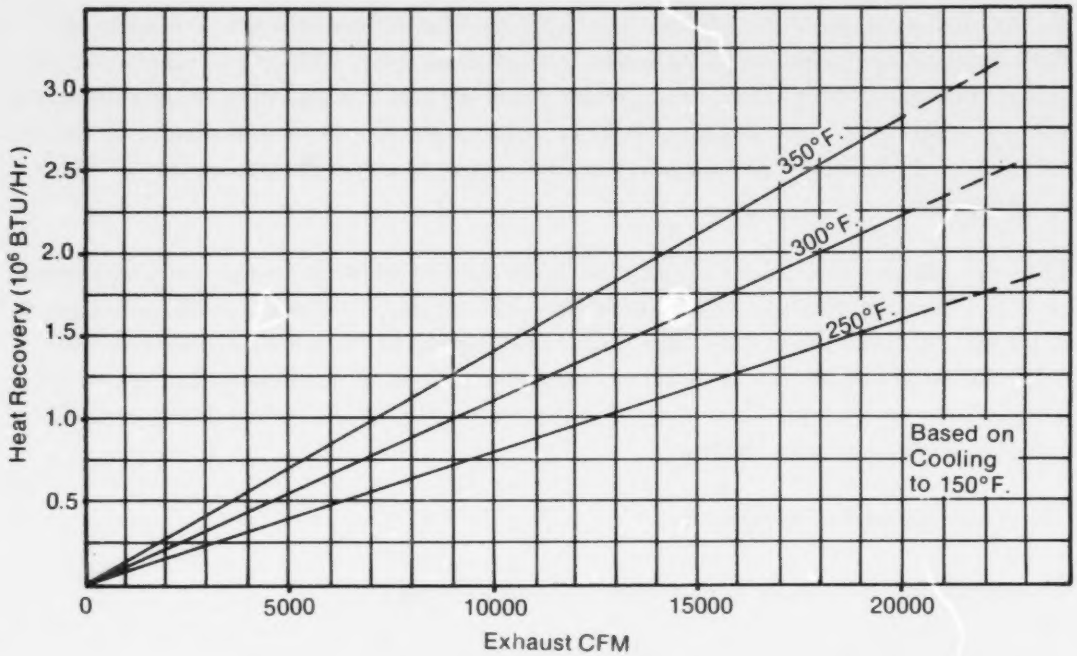


FIGURE 9-27

RECOVERABLE BTU/HR. VS. CFM EXHAUST

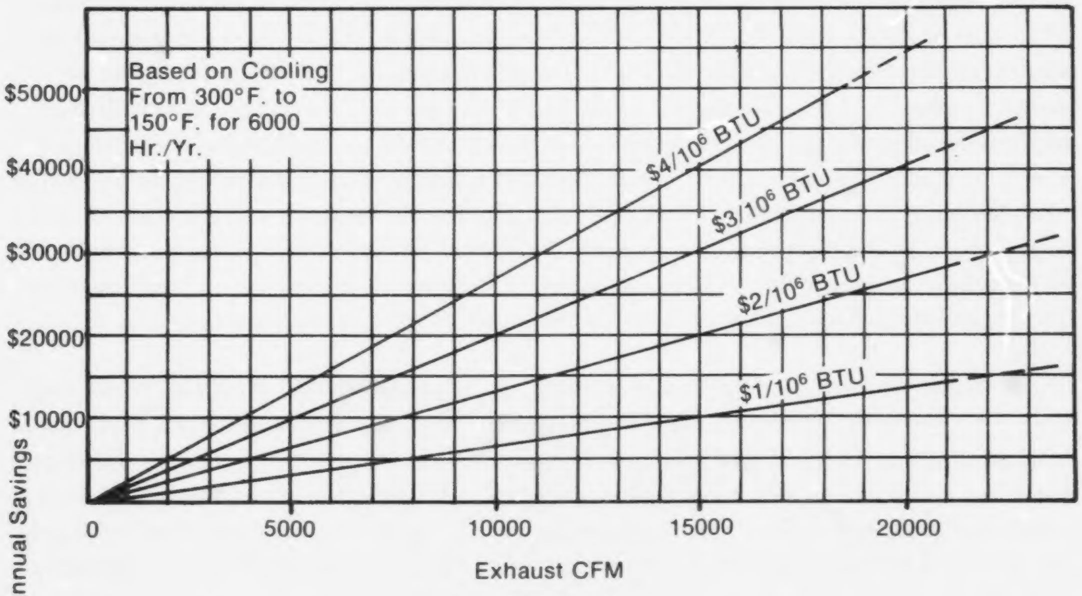


FIGURE 9-28

ANNUAL SAVINGS FROM HEAT RECOVERY

Source: Lockwood Greene Engineers, Inc.

On the other hand, the inefficiencies of the heat generation system must also be considered. With direct gas fired ovens, assuming complete combustion, every BTU of heat value in the gas will produce one BTU of heated air in a tenter, but if the heat is produced by steam coils heated with an oil fired boiler, the number of BTU's required in the process must be divided by the efficiencies of the boiler and the steam transmission system to obtain the true number of BTU's of oil required.

From the estimates of net annual savings, the maintenance cost of the heat recovery equipment must be subtracted. In cases where an oil laden exhaust is cooled below the condensation point of the oils, gums and waxy solids, these costs can be significant. However, in cases where the exhaust must be cooled anyway for mist condensation, the installation and operating costs of a heat recovery system must be compared to the alternative cost of a system simply designed to cool the exhaust and waste the heat.

9.4.2 General Considerations

The generalized equation for heat recovery in a heat exchanger is:

$$Q \text{ (BTU/hr)} = hA \ (T_1 - T_2) \qquad (9.11)$$

where T_1 and T_2 are the temperatures of the hot and cold streams at the point of heat transfer, A is the effective heat transfer area, and h is a heat transfer coefficient to account for the various resistances to heat flow. It can be seen that the amount of heat recovered can be increased by increasing A or h, while $(T_1 - T_2)$ is the driving force for heat flow and is a measure of the amount of heat that has not been recovered from the hot stream. Effective heat transfer area can be increased by increasing the size of the heat exchanger or increasing the complexity of the heat transfer surface. The heat transfer coefficient will be increased by increasing the degree of contact of the hot exhaust air with the heat exchanger surface, preventing the formation of an insulating layer of stagnant air along the surface. Use of a heat recovery fluid such as water instead of air results in decreased resistance to heat flow. Condensation of oils and waxes on the heat exchanger surface reduces the heat transfer coefficient by formation of an insulating layer. This reduction must be considered in estimation of the size of heat exchanger required.

The preferred heat exchanger type varies with the characteristics of the exhaust air stream and the use for which the recovered energy is intended. For most exchangers recovering heat from exhaust air, maintenance of the equipment in clean condition for efficient operation will be an important consideration. Since cooling lowers the temperature of the exhaust air in the vicinity of the heat exchanger surface, oils, waxes and gums can deposit on the surface, resulting in gradual and often unnoticed losses in heat exchanger performance and in extreme cases in plugging. A lint screen or filter should be placed before the heat exchanger inlet. If large amounts of lint are expected, this should be of the self cleaning variety (see Section 9.7). Provisions for drainage and collection of condensed oils must be provided. Internal cleaning equipment for cleaning with steam, hot water or detergents is necessary with exhausts that can gum or solidify. In addition, provisions should be made for easy manual cleaning from time to time for removal of accumulated solid deposits (33).

Three basic types of heat recovery systems exist: air-water exchangers, where heat is transferred between air and water; air-air exchangers, where heat is transferred directly to another air stream; and heat exchangers, which transfer heat to an intermediate working fluid for subsequent utilization.

9.4.3 Air-Water Exchangers

Air-water exchangers are useful for preparing heated process water for dyeing, washing, etc. The heated water can be stored in a reservoir, and supplemental heat can be provided there so that the operation of processes requiring hot water is not dependent on simultaneous operation of the process producing hot exhaust air.

Air-water heat exchangers have the advantage of small size and ease of control. A hot water finned tube exchanger that can cool a 6,000 CFM air flow from 300 to 150° F, producing 17 gpm of water heated from 60 to 80° F measures 4½ by 3¼ by 3 inches (33). Water flow rates can be controlled relatively inexpensively, and ambient water is subject to less seasonal temperature variation than ambient air. Initial costs for air-water heat exchangers are generally lower than for air-air heat exchangers.

Hot water produced must be used immediately, disposed of or stored. It is generally not possible to expect that all hot water produced can be used immediately. Storage facilities, if not already present, may add more to the cost of the system than can be justified by the expected savings. Disposal can present thermal pollution problems in some areas and can result in excessive cost for plant input water.

Coils consisting of bare tubes or finned tubes can be used for the exchanger. Bare tubes are easier to clean but require a larger sized exchanger because of their smaller surface area. For most textile applications with relatively clean exhausts, finned tubes with fin spacings of 6 to 10 fins per inch can be employed. Countercurrent heat exchangers are slightly more expensive than the concurrent type, but they are more efficient and can produce outlet water temperatures higher than the outlet air temperature. The water system must be provided with a drain which is either insulated or located inside the building to prevent freezing (33).

9.4.4 Air-Air Exchangers

Air-air exchangers can be used to recover heat for reuse by the process, or for plant heating in the winter months. If more heat is recovered than can be used, the rest can simply be wasted. If the heat exchanger is used to recover heat for return to an oven, some of the returning hot air may have to be directed elsewhere. Most ovens require a negative pressure to prevent the escape of smoke and odors into the room. Preheated air may also be too hot to pass through a burner where the fan is mounted directly (33). During the summer months, higher outside air temperatures (up to 100° F) require that a larger volume of cooling air be used per CFM of exhaust than is true in the winter, and some additional cooling with water may be required to reduce the exhaust to the required temperature for oil mist elimination. The three types of commonly used air-air heat exchangers are tube type exchangers, heat wheels, and heat pipes.

Tube type heat exchangers are the simplest in design and lowest in cost, with hot and cold air alternating either inside or outside the tubes. With oil and dust laden emissions, where buildup is likely to occur, contaminated air should be kept on the side that is easiest to clean. For those with slide out racks that can be cleaned, or those with integral wash systems, this would be the outside of the tubes, while for finned tubes, the tube insides might be easier to clean. Due to the relatively large surface area required, size and weight considerations limit heat exchange efficiencies to 35 to 50% (33).

Heat wheels or rotary heat exchangers are fairly light weight and have high efficiencies. As co-current heat exchangers, close mesh heat wheels approach 80% efficiency for clean exhausts. Experience to date with heat wheels has not been favorable in the textile industry. This type operates by rotating a closely packed metal mesh wheel through adjacent hot and cold ducts. The metal mesh picks up heat as it rotates through the hot duct and then gives up its heat as it rotates back through the cold duct. Air exchange between the two ducts is claimed to be as low as 3%.

Since close packed metal mesh heat wheels are constructed like filters, they cannot be used on exhaust streams where fouling is likely to be a problem. This would include any mist laden exhaust from which gummy or waxy contaminants would condense in large quantity. Some designs provide built in cleaning facilities which will allow operation on exhausts from which relatively freely flowing oils condense. However, even in this case, efficiency is reduced by condensation of the oil on the mesh. Metal mesh heat wheels also permit mixing of the two streams, which allows mist and oil buildup in the clean air intake ducts. This is a maintenance problem at best and a potential fire hazard. It is undesirable if the air is to be used for in-plant heating.

Figure 9-29 shows another type of heat wheel, consisting of preshaped channels separated by rotary seals. A purge from the clean air intake sweeps the first chamber on the clean side, sending the dirty air back into the exhaust to reduce mixing to below 1% (34). Because of the relatively low surface area of this design, heat transfer efficiencies are lower than with the metal mesh type.

Heat pipes (see Figure 9-30) are probably the most expensive heat transfer system, costing about $2.00 per CFM in 1974, although installation costs are not high. Typically, heat pipes are constructed from aluminum or copper, with plate or spiral fins on the outside in contact with the air streams. Inside is a heat transfer fluid selected for the temperature range to be encountered. (Water is used in the 150 to 400° F range.) The fluid condenses on the cold side,

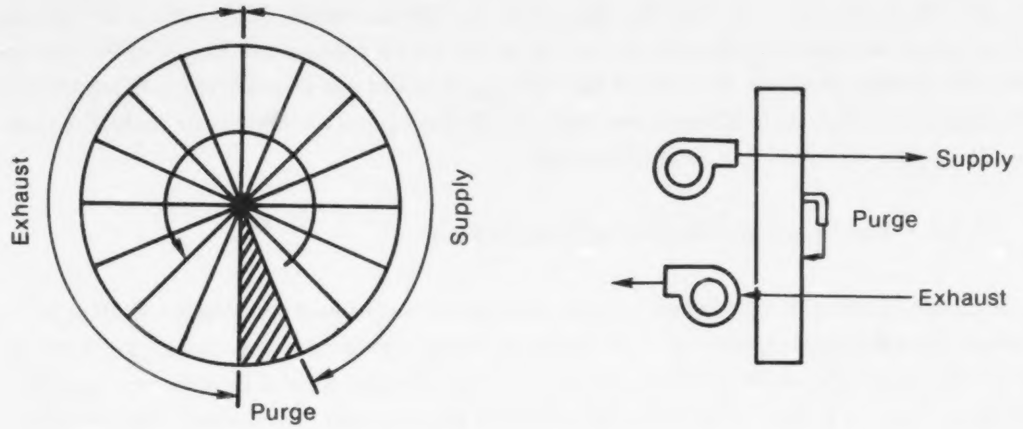

Exhaust
Supply
Purge
Supply
Purge
Exhaust

FIGURE 9-29
ROTARY SEAL HEAT WHEEL

Source: Lockwood Greene Engineers, Inc.

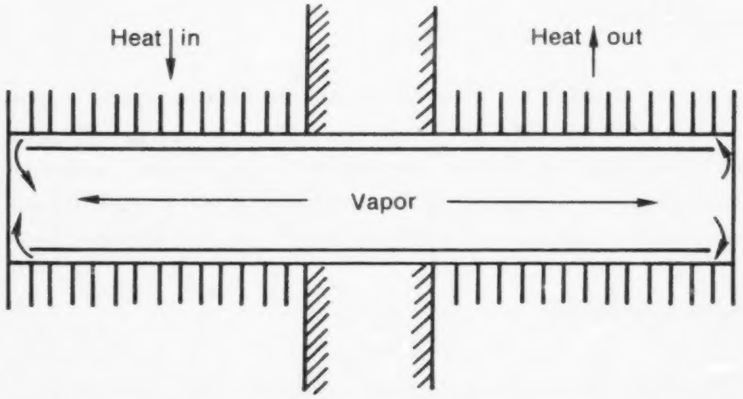

Heat in
Heat out
Vapor

FIGURE 9-30
HEAT PIPE

Source: Lockwood Greene Engineers, Inc.

sticks to the hot side, and evaporates. Very high transfer rates and an extremely uniform internal temperature result; however, like other tube and finned tube heat exchangers, their heat transfer efficiencies are limited by the film coefficient on the outside of the tube. Condensation of oils, gums and waxes on the exhaust air side of the finned tubes causes loss of efficiency and difficult cleaning problems. Because of this, heat pipes would not be preferred for heat transfer involving dirty exhaust air. Maintenance costs for the heat pipes themselves are no higher than for other types of finned tube heat exchangers.

9.4.5 Heat Exchangers Employing Transfer Fluid

Additional flexibility in heat recovery is provided by the use of heat transfer fluids. Heat is recovered from the exhaust gases in a finned tube exchanger similar to an air-water exchanger. It heats a transfer fluid which circulates in a closed system, being pumped through one or more additional heat exchangers where it gives up its heat to air or water as required. Process water can be heated on demand, or make-up air can be heated for the oven. Plant air can be heated with the thermo-fluid, or the heat can simply be wasted. Use of ambient water for cooling in the summer allows more effective cooling of the exhaust than would use of hotter ambient air. Heat can be pumped for long distances through properly insulated piping with relatively little loss. Operation below the freezing point or above the boiling point of water is also possible.

Systems using transfer fluids are inherently more costly and less efficient than single exchanger systems, since there are at least two heat exchangers and an entire recirculating system involved. They are most effective for recovering large quantities of high temperature heat for use at multiple points.

9.5 Solvent Recovery

Following each process in which textile materials are treated with organic solvents, the solvents are driven off, generally by hot air drying, and then are recovered by condensation followed by adsorption on activated charcoal. Solvent recovery systems are more complex and expensive than other pollution abatement systems, costing for installation $5.00 to $20.00 per CFM of treated air (1974 prices), but they can usually be justified by process cost savings (11).

9.5.1 Process Description

Figure 9-31 details the complete solvent recovery system for a typical continuous dry cleaning system using a chlorinated solvent. The system removes the solvent from the dry cleaned fabric by countercurrent hot air evaporation. Effluent air is cooled to 100° F, during which time most of the solvent is recovered by condensation. Since temperatures below 100° F are required for adsorption of organics onto charcoal, it is necessary to perform the final precooling with refrigerated water during the summer months.

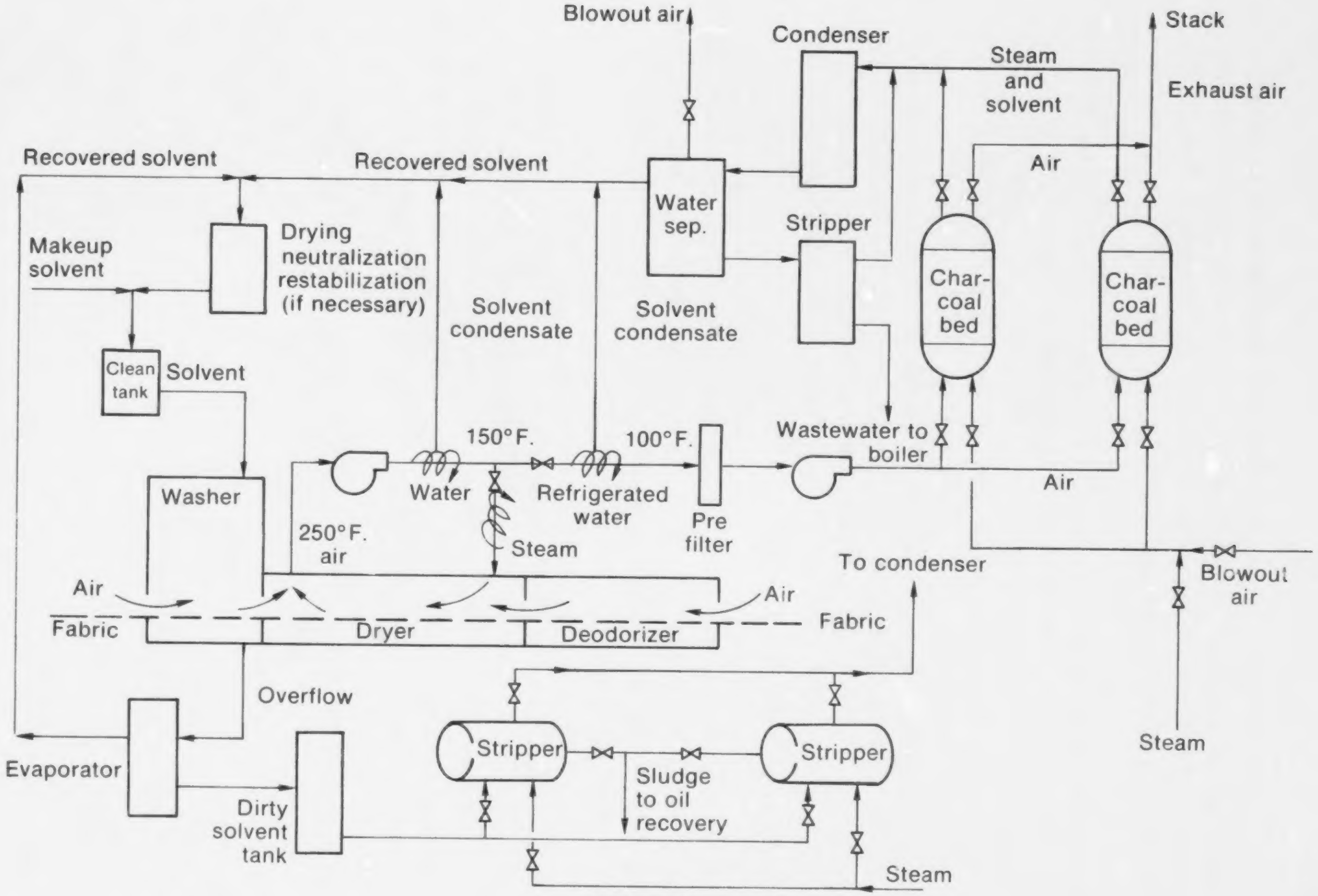

Blowout air
Condenser
Stack
Steam and solvent
Exhaust air
Recovered solvent
Recovered solvent
Air
Water sep.
Stripper
Makeup solvent
Drying neutralization restabilization (if necessary)
Char-coal bed
Char-coal bed
Solvent condensate
Solvent condensate
Clean tank
Solvent
150° F.
100° F.
Wastewater to boiler
Washer
Water
Refrigerated water
Air
250° F. air
Steam
Pre filter
To condenser
Blowout air
Air
Air
Fabric
Dryer
Deodorizer
Fabric
Overflow
Evaporator
Stripper
Stripper
Steam
Sludge to oil recovery
Dirty solvent tank
Steam

FIGURE 9-31

TYPICAL SOLVENT RECOVERY SYSTEM FOR CONTINUOUS DRYCLEANER

Source: Lockwood Greene Engineers

Prior to the charcoal beds, a pre-filter must be employed to remove lint and entrained oils from the effluent air. This pre-filter can also include a small sacrificial bed of charcoal to remove catalyst poisons.

The charcoal beds operate in parallel; one adsorbs solvent from the effluent stream while the other is being steam stripped. For each pound of solvent adsorbed, about 10 pounds of charcoal are required per bed, and from 3 to 6 lbs. of steam are required for stripping. Following stripping, air is blown through the bed for at least 1 minute to exhaust the steam.

The steam is condensed and sent to a water separator, from which the recovered solvent is decanted. If the solvent is significantly soluble in water, as is the case with methylene chloride, a stripper can be used to remove it from the wastewater, which can itself be recycled to the boiler. For completely miscible solvents, the stripper would be used in place of the water separator.

If the recovered solvent cannot practicably be recycled and if it does not contain chlorine, fluorine or sulfur, the steam-hydrocarbon mixture can be sent directly to an incinerator. Calculations have shown that in this case, the necessary heat for incineration can be obtained almost entirely from combustion of the solvent vapors. Exhaust heat from this process can be used to generate the steam necessary for stripping (35).

With stabilized chlorinated hydrocarbons, some stabilizer loss is encountered on recovery. Except in the case of 1, 1, 1, trichloroethane, stabilizer losses are not appreciable at recycle ratios below 75%, but above that level, restabilization must be performed, or an especially heavily stabilized solvent must be employed.

With 1, 1, 1, trichloroethane, the stabilizer is almost completely lost during steam stripping, resulting in a highly corrosive liquid that must be dried, neutralized and restabilized before reuse. Special materials are equipped for such systems. Pre-packaged systems that can handle 1, 1, 1, trichloroethane are available at a slightly higher cost than is available in standard systems. Despite this extra cost, economics may still favor recovery of 1, 1, 1, trichloroethane.

Process requirements for a 1000 CFM system are quoted by one manufacturer as follows:

Carbon	300-500 lb.
Steam	400 lb./hr
Water	670 gph
Electricity	14 amps at 220 volts

The pressure drop necessary is about equivalent to that for a low energy scrubber (11).

In addition to recovering solvent from the drying air, many commercially available solvent recovery systems clean and recycle the dirty wash liquid. Wastes are concentrated in an evaporator fed from the dry cleaner overflow and then are steam stripped. The remaining sludge contains dirt and spinning oils that can be recovered for use as heating oils if all chlorinated solvents have been stripped out.

With solvent recovery systems, sludge disposal requires consideration. Commercial reprocessors, where available, can alleviate the problem by further solvent reclaiming and diminishing sludge volume.

9.5.2 Installation and Operation

Pre-packaged solvent recovery systems are commercially available at capacities of up to 4,000 lbs/hr of solvent or 200,000 CFM of air for most commonly used solvents, and are often included with the solvent processing machinery itself. Purchase of one of these is generally cheaper than engineering and construction of a tailor-made system. However, before purchase it is wise to consult with other users of the systems under consideration, as some commercial solvent recovery systems do not perform according to the manufacturer's promises under mill conditions. Because of the complexity of the recovery system, it is also recommended that the mill have at least one person in house who is experienced in its operation and understands the principles by which it operates.

Solvent detection devices should be installed permanently at the fabric inlet and outlet slots and at the stack and at any other point where leaks are likely to occur. Automatic analyzers vary in price from $800 to $3,000 each (1974 prices) and can be powered to drive recorders, ring bells, etc. A portable analyzer, such as propane halo-torch, is also recommended for spot checks of the entire system. Leaks can be caused by machinery vibrations, poorly or improperly fitted couplings and flexible hoses, kinks in hoses, failure of door seals on machines, or malfunctions in the recovery system.

OSHA has set the following 8-hour average exposure limits for some of the commonly used solvents: (36).

Benzene	10 ppm
Carbon tetrachloride	10 ppm
Xylene	100 ppm
Trichloroethylene	300 ppm
Perchloroethylene	100 ppm
Methyl Alcohol	200 ppm
Toluene	200 ppm
1, 1, 1, trichloroethane	350 ppm
Ethyl Acetate	400 ppm
Acetone	1000 ppm

Maximum exposures of 300 ppm for 5 minutes of each 3-hour period are allowed for perchloroethylene (37).

Ethylene, xylene, trichloroethylene and toluene are considered photochemically active. Perchloroethylene or 1, 1, 1, trichloroethane are recommended as substitutes for trichloroethylene. (36).

Contact of chlorinated hydrocarbon vapors with open flames should be avoided, as hydrogen chloride and small amounts of phosgene are generated. If solvent contaminated air is drawn into gas fired tenters, etc., the hydrogen chloride thus generated could cause browning of cotton and dye degradation resulting in off-shade goods. The initial concentration of perchloroethylene for this is estimated to be 200 to 500 ppm (37).

When chlorinated solvents such as perchloroethylene, trichloroethylene, methylene chloride, and especially 1, 1, 1, trichloroethane are steam stripped, hydrochloric acid is present in the bed. Since the activated carbon has catalytic properties, corrosion problems can be severe, and 304 or 316 stainless steel is not acceptable for carbon beds to recover chlorinated solvents. Most carbon adsorption systems are therefore lined with baked phenolic. A carbon bed for methylene chloride recovery with a baked phenolic coating can last 20 years under these conditions, while a bed of 304 stainless steel would last only 3 months.

Solvent losses are claimed by manufacturers to be 1 to 3%, but 5 to 8% may be a more realistic figure. Larger losses, of up to 20%, may be expected during startup (37). Some commonly experienced problems with solvent recovery systems are listed below:

- Overloading of the charcoal beds because of insufficient cooling of the inlet air. Inlet temperatures of 100° F or lower are necessary, since the amount of solvent in solvent saturated air increases with temperature and the capacity of the charcoal to adsorb it decreases. The refrigeration system must be designed for conditions during the warmest summer months.
- Inadequate stripping of the waste oil-sludge mixture due to poor contact between the stripping steam and the sludge and failure to optimize the stripping cycle. Since the stripping rate is controlled by the rate of diffusion of the solvent from the sludge to the steam bubbles, the steam must be evenly and finely dispersed.
- Pressure-flow instabilities due to inadequate provisions for venting, siphoning, unstable control loops, etc. If these are not corrected, they can cause inefficiency and operational failure.
- Emulsions in the water separators due to introduction of surfactants, dirty water and solvent, etc.
- Squeeze roll deterioration (37).

The use of activated carbon and other adsorbents for selective adsorption of vapors from an exhaust is discussed in greater detail in Section 9.2.2.4, and in the EPA Air Pollution Manual (8), pp. 189-199.

9.6 Odor Abatement

9.6.1 Introduction

Odor pollution may be defined simply as "the development of any substance that affects our olfactory organs in a disagreeable manner" (38). As such, it is a highly subjective problem, since an odor that is disagreeable to one person may not be so to another. Further, the concentration at which a substance must be present in the atmosphere to create disagreeable odors varies widely from compound to compound. The odor recognition threshold for some tests is defined as that concentration at which 100% (or as low as 50% in other tests) of those present in an odor panel can smell and identify a particular odor (39). Listed below are the odor recognition thresholds of a few common odor causing substances (38).

Methyl methacrylate	0.2 ppm
Monochlorobenzene	0.21 ppm
Aniline	1.0 ppm
Formaldehyde	1.0 ppm
Hydrogen sulfide	0.00047 ppm

Odors may consist of vapors, of liquid mists, or of particulates with adsorbed odorous substances. If the odorous substance is not present in significant quantities in the vapor phase, odor abatement can be carried out by the techniques for mist and particulate removal detailed in Section 9.3. In some cases, techniques for visible emission reduction and odor abatement must be combined. The presence of visible mists or particulate emissions, either carrying an odor or accompanying it, can increase the nuisance factor of the odor by drawing public attention to it.

Common textile processes and substances that cause odor problems include aqueous polyester dyeing, where most of the carriers have extremely annoying odors at low concentrations. These cause problems not only at dyeing, but at subsequent drying steps. Commonly used odorous carriers are ortho phenyl phenol, methyl salicylate, trichlorobenzene, ortho dichlorobenzene, biphenyl, butyl benzoate and the menthyl naphthalene sulfonates (39). Of these, the most important and possibly the most disagreeable is biphenyl. Finishing operations to impart flame proofing, rot proofing, water repellency, crease resistance, etc. often employ odorous (and proprietary) compounds (26). Gradual release of formaldehyde from the finish resins can cause odor problems.

Other sources of odor are solvents used in solvent processing, which is discussed in detail in Section 9.5, defoamers used in some dyeing and printing processes, sulfur dyeing of cotton and cotton blends, reducing or stripping dyes using hydrosulfites, bonding, laminating and backcoating operations, and bleaching with chlorine dioxide.

Most enforcement agencies today handle odor problems on a complaint basis. It is therefore best to apply odor abatement techniques before the public is aroused. Once the odor source has been identified, dilution, reodorization, or partial abatement may not be acceptable to neighbors who have become accustomed to being offended by it.

Abatement techniques vary with the nature of the odor causing substances and other accompanying pollutants. For selection of the best technique for each particular process, it is necessary to know the CFM, temperature and approximate contaminant concentration and composition of the air to be processed. Mist and particulate concentrations in the effluent air should be known, as well as water vapor concentration, since some odor abatement techniques will not function under certain conditions or when subjected to some pollutants (11). The options include:

- Process or chemical substitution and housekeeping improvement
- Dilution
- Masking or modification
- Scrubbing
- Dry adsorption
- Incineration

Odor-laden air is drawn off the process and is ducted to the odor abatement system. Since odor abatement costs are directly proportional to the volume of air to be processed, hooding and venting should be designed to remove odors with a minimum of dilution air (11).

9.6.2 Process Modification or Chemical Substitution

Odor problems can often be eliminated or reduced if the processes involved are modified so that the odor causing chemicals are eliminated or emitted in smaller amounts, or so that other vapors are emitted which are either less odorous or easier to remove from the atmosphere.

In the case of polyester dyeing, pressure dyeing will produce fewer odor problems than atmospheric dyeing, since the required carrier concentration is lower. Substitution of solvent dyeing for aqueous dyeing can eliminate carrier odors, since no carrier is necessary with solvent systems. With existing processes, where major changes in equipment would not be feasible, it is often possible to substitute less odorous carriers, or carriers that are easier to mask or to treat with inexpensive techniques. Optimization of carrier concentration and of the time-temperature cycle for dyeing can sometimes result in decreased carrier consumption.

In cases where the odorous compound is generated in the process or is present in excess concentration, it can sometimes be removed by addition of chemicals that will react with it. One example is the use of formaldehyde acceptors to react with the excess of free formaldehyde present in resin finishing. This example also illustrates the limitations of such a solution because in some cases the formaldehyde acceptors will also react with formaldehyde in the resin itself, destroying fabric properties such as wash-wear and smoothness. If this reaction continues during storage of the fabric, amine odors are produced. Formaldehyde acceptors have been used successfully for many years, but they require extreme care in application (39).

Good housekeeping and proper maintenance of existing antipollution equipment can alleviate some odor problems. Proper adjustment of air flow rates to the odor abatement system can sometimes result in reduced volumes of air to be processed and, therefore, in greater efficiency of odor removal at lower operating cost.

With solvent recovery systems using activated charcoal, there are generally no odor problems if they are properly sized, operated and maintained. See Section 9.5 for details.

In some cases, an odorous compound is applied to the fabric that comes off gradually in later processes. Immediate and thorough drying can result in this compound's removal at a single location, simplifying odor collection problems. There exist non-odorous deformers that perform as well as the odorous ones. Other oxidizing agents can sometimes be substituted for chlorine dioxide in the bleaching process.

9.6.3 Dilution

Dilution of the effluent air can alleviate odor problems in cases where the odorant concentration is already relatively close to the odor recognition threshold and where emissions do not exceed overall limits for hydrocarbon emissions in general or for emission of the specific compounds in the exhaust. Since the purpose of dilution is to reduce the concentrations of odor causing emissions to acceptable levels at all points outside the plant boundary at ground level, it is most effective if the stack is located at the furthest possible distance from potential sources of complaint. In most cases, this will be the center of the plant property.

Under normal atmospheric conditions, pollutants spread from a point source, such as the outlet of a stack, in a roughly parabolic pattern for the first two miles (40) (see Figure 9-32). This means that the radius of the plume increases as the square root of the distance from the stack, and the pollutant concentration, which varies inversely as the cross-sectional area of the plume (or as the square of the cross-sectional radius), decreases linearly with distance.

$$C = K_1/X \qquad (9.12)$$

In the event of an inversion, where a warm air layer overlies a layer of colder ground air preventing upward dispersion of the plume, pollution is trapped below the inversion level, and pollutant concentration at the ground decreases only as the square root of distance.

$$C = K_2/X^{1/2} \qquad (9.13)$$

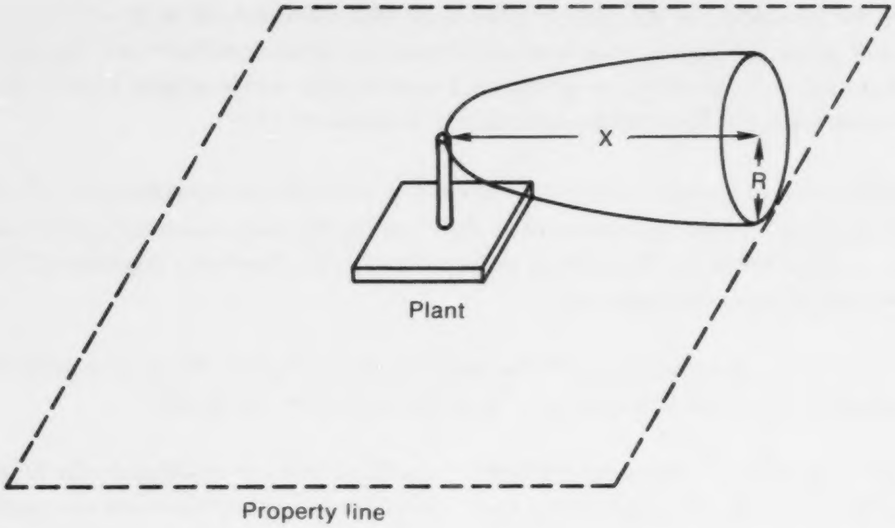


FIGURE 9-32
SPREAD OF CONTAMINANTS FROM A STACK

Source: Lockwood Greene Engineers, Inc.

The effective height of a stack is defined as the true height, plus a correction factor for exhaust exit velocity and the buoyancy due to its higher than ambient temperature. Increasing the effective stack height increases the dispersion distance of the pollutants before they reach the ground. Correlations for maximum pollutant concentration at the ground as a function of stack height differ for various weather conditions, but in general, maximum pollutant concentration at ground level decreases more slowly than would be expected if it were inversely proportional to stack height (40). Increasing the effective stack height also increases the probability that the emission will break through any inversion layer and be carried away by the warmer upper air.

Addition of diluent air to the exhaust air will have a slight effect, as it will reduce the pollutant concentration at the stack outlet and will increase the effective stack height slightly by increasing the stack velocity. However, the total amount of odorant release will not be decreased, and the additional volume of dilution air will be small in proportion to the volume of outside air with which the odorant will mix naturally downwind of the stack. It is generally not economical to try to increase the effective stack height by increasing either the exhaust velocity or temperature. However, combining two exhausts into one higher stack will increase both the true stack height and the velocity correction, and is worth considering (40).

9.6.4 Masking and Modification

Odor masking and modification are accomplished by adding small amounts of a reodorant, either to the process bath itself or to the exhaust air. The purpose is to render the final exhaust odor more acceptable, either by overpowering the initial odor with the reodorant, or by "marrying" the two odors to form a third odor of lower odor profile for greater acceptability. If the odor modifier is added to the process itself, care must be taken that it does not alter the process chemistry unfavorably. Since the original substance is not destroyed or modified, this technique cannot be used for toxic or physiologically irritating fumes or odors whose presence is necessary to detect leaks and malfunctions, such as hydrogen sulfide in natural gas. Furthermore, the reodorant may have different properties from those of the original odorant and can sometimes become separated from it during atmospheric dispersion (11).

Where applicable, odor neutralization has the advantage that initial equipment costs are low, negligible space is required, and the odorous air need not be contained or collected. Operating costs are also low. Generally 0.25 to 1% reodorant is employed, based on the weight of the initial odorant (11), (39).

Odor masking is accomplished with a chemical that has a distinctive or overriding odor such that it hides the original malodor. In some cases, this can be done successfully, but in many cases a sweet or perfumed odor results that can become as objectionable as the original malodor. This has become known as the "Persian Bordello" effect (38).

Odor modification, on the other hand, seeks to blend the original odor with a second specific odor to produce an odor that is either reduced or at least more acceptable. Commonly used reodorants include mixtures of aldehydes, ketones, essential oils, etc., such as citronellin, vanilin, oil of sandlewood, oil of cedarwood, or piperonal (38). For each specific odor, a uniquely tailored combination of reodorants is employed.

Reodorants have been successfully used to alleviate odors from polyester dye carriers, such as biphenyl. Typically 0.75 lb of reodorant is used per 100 lbs of carrier, half being added to the dyebath at the start of the dye cycle, and the rest 1 hour later. The reodorant reduces carrier odor by simultaneous evaporation, both during dyeing and subsequently during drying. To eliminated odors during heat setting, 0.25 lb of reodorant per 100 lbs of carrier can be added during the final rinse (38), (39).

Reodorants are also available for the synthetic latexes and emulsions used in the carpet industry, for elimination of sulfide odors from sulfur dyeing, for bonding and laminating, for fluorocarbon oil and water repellent finishing, for fire retardant finishing, and for control of formaldehyde odors from resin finishes, both during resin application and during subsequent storage of the finished fabric (39).

9.6.5 Scrubbing

Virtually all odors can be eliminated from exhaust air by scrubbing, either with water or with a chemical solution to dissolve and then destroy the odorant. In cases where the effluent contains both oil mists and odors in the gaseous phase, pre-cooling prior to mist elimination (see Section 9.3.5) can be accomplished in a packed tower, by a cooling coil or in a low energy wetted filter scrubber, which doubles as a means of odor elimination. Addition of a water spray to a mist eliminator can cause it to function as a packed tower for gas adsorption, thereby removing odors and oil mists at once (30). Several firms sell prepackaged units consisting of a pre-filter, a scrubber, and an electrostatic precipitator. The principal disadvantage of scrubbers for odor removal is that they present a potential liquid disposal problem, especially if organic solvents or aqueous chemical solutions are used for the scrubbing.

In odor abatement applications, scrubbers function by adsorption of the contaminant by the scrubbing liquid, followed in some cases by chemical reaction of the contaminant, either with dissolved solutes or with the scrubbing liquid itself. Therefore diffusion, especially through the gas phase, and absorption tend to be rate limiting, and maximization of gas-liquid contact is essential. Spray towers, which are used primarily to cool gases, and impingement type scrubbers, which are useful for removal of large particles by impaction on wetted surfaces, give little gas-liquid contact. Venturi scrubbers and other types of high energy scrubbers are used primarily for removal of mists and fine particulates (see Section 9.3.7). Packed towers are preferred for odor absorption because of their large wetted surface areas.

Packed towers are available with various shaped packings to obtain intimate air-liquid contact. They can be plugged with high particulate loadings and may require a pre-filter for removal of lint. In some applications, a Venturi scrubber is used for elimination of particulates prior to a packed tower scrubber. If chemical scrubbing is used, removal of the particulates prior to scrubbing minimizes the chemical costs by removing a substantial fraction of the reactive material beforehand. The marble bed scrubber scrubs vapors with a bed of rotating, self cleaning marbles, combining to some extent the absorption properties of the packed bed and the particulate removing properties of the Venturi (11). Operating costs of packed towers and other low energy scrubbers are low because of the low pressure drop required. If chemicals or organic solvents are used for the scrubbing, these costs are additional.

Installed costs of the various types of scrubbers in 1974 were: (11)

Packed towers:	\$0.25 – \$1.00/CFM
Spray chambers:	\$0.25 – \$0.50/CFM
Other low energy scrubbers:	\$0.50 – \$3.25/CFM
Venturi scrubbers:	\$0.50 – \$4.00/CFM (and operating costs approach those of fume incineration)

Chemicals are often added, either in solutions or as slurries, to destroy the absorbed pollutant after absorption. This eliminates the necessity of subsequent disposal of the pollutant itself (though the reacted solution must be disposed of or recycled) and increases scrubbing efficiency, since liquid phase resistance to absorption is eliminated and the solution never approaches saturation with respect to the pollutant. Lime slurries neutralize acidic effluents such as HC1 or SO_2, and dilute sulfuric acid is used to react with nitrogen bases (26). Oxidizing agents used include sodium hypochlorite, chlorine, chlorine dioxide, ozone, potassium permanganate, and dichromates. Chlorine, chlorine dioxide, and ozone are pollutants in themselves, but they have been used successfully in some instances. Hypochlorite and dichromate solutions are not strong enough oxidizing agents for some odors (11).

Potassium permanganate has been used to abate odors from a wide variety of organic compounds. It is a readily soluble purple crystalline solid costing about 50 cents per pound (1975 prices). As it is reduced in solution, it loses its purple color, becoming pink and then brown and finally precipitating as an insoluble black-brown sludge of manganese dioxide, which must be cleaned periodically from the system. Potassium permanganate solutions are non-corrosive to most metals and plastics in their optimum operating pH range of 8.9 to 9.5. Buffers such as sodium bicarbonate or borax can be used to maintain this pH, especially in cases where adsorption of atmospheric carbon dioxide causes a drop in pH. Optimum permanganate concentration for scrubbing is usually 1 to 2% wt. Typical operating costs for a potassium permanganate wet scrubbing system range from $5.00 to $100.00 per day for 20,000 CFM (1974 prices) (11).

In cases where odorants have very little solubility in water, scrubbing can be performed at greater expense with an organic liquid. Stripping oils with vapor pressures of below 0.1 mm of mercury are recommended. These can be steam stripped and recycled, and the odorant can be either recovered from the exhaust steam after condensation or fed directly to a fume incinerator (41).

9.6.6 Dry Adsorption

Adsorption of pollutants from an effluent stream can be used either to concentrate the pollutants for subsequent recovery or disposal, or for direct chemical catalytic destruction of the pollutants. Of the various available adsorbents, activated carbon is the most widely used, as it is non-selective but adsorbs organics in preference to water. Other common adsorbents such as silica gels, synthetic zeolites, and metallic oxides are more selective in the type of odorants they will absorb, and will generally adsorb water in preference to organics (11), (26).

Activated carbon systems are discussed in detail in Section 9.2.2.4. They are expensive for high flow rates and in cases where recovery of the adsorbent is not practical.

Initial installed costs run from $5.00 to $20.00 per CFM, but due to the low pressure drop, operating costs are not high, unless the carbon must be sent back for regeneration (11). Pollutants are collected, but must be subsequently steam stripped and disposed of. When used solely for the removal of low concentrations of odorants generated intermittently, such as carrier odors from polyester dyeing, an activated carbon system consisting of a single bed would be feasible. Steam stripping of the pollutant would be performed during times when the odorant was not being released by the process.

9.6.7 Incineration and Chemical Destruction

Direct fume incineration is the most proven and accepted method of odor control and can be used in all situations except for those where the exhaust contains high concentrations of compounds containing chlorine, fluorine or sulfur, which would be converted to the extremely odorous and corrosive compounds HC1, HF, and SO_2, respectively. In this case, scrubbing would have to follow incineration. Incineration has not always been economical for flow rates above 5000 CFM, since operating costs are high: $1.00 to $2.00 in 1974 per hour per 1000 CFM for direct fume incineration without heat recovery (11). Incineration is often used for destruction of an effluent that has been concentrated by some preprocess, such as charcoal adsorption.

Catalytic incineration requires less energy than direct fume incineration, because it takes place at a lower temperature, but equipment costs are higher, and the catalyst requires periodic replacement or reactivation. The nature of the odor causing impurities must also be known before specification of a catalytic system, as some catalysts are deactivated by some impurities.

Chemical destruction of odorants can be used if the odorants are present in very low concentration. The odorant is first adsorbed onto granules of the reactive chemical or onto an inert support that has been impregnated with the reactive chemical, and then it is destroyed, being used up in direct proportion of the odorant destruction.

Incineration and chemical destruction are discussed in detail in Section 9.2.1.

9.7 Lint and Dust Removal

Lint and dust are processed in greatest quantity by spinning and the processes preceding it, and by shearing, napping, and singeing. With the exception of singeing, these processes produce very little atmospheric pollution and other than dust and fly, and they do not drastically change the temperature and humidity of the air exhausted from them. Since each of these processes has an optimum temperature and humidity, it is generally more economical to remove the particulates from the exhaust air and to recycle it to the same area than to send the exhaust to the outside and to bring in fresh air which must be brought to the optimum conditions (42).

Of all types of particulates, the most undesirable is cotton dust, because of its potential for causing byssinosis. OSHA regulations presently limit the quantity of cotton dust to 1.0 mg/m^3 per cubic meter (4.37 x 10^{-4} grain/AFC). Dust levels above 3 mg/m^3 are considered a serious violation. Permanent standards have not yet been set, and they may be reduced to 0.5 mg/m^3 or even lower. It is, therefore, wise to purchase dust removal systems that can be increased in efficiency as regulations become more stringent.

The cotton industry is currently attempting to develop strains of cotton with a lower trash content, and it is investigating methods of trash removal during ginning and ways of rendering the remaining trash less objectionable (43). However, it is unlikely that these efforts will entirely solve the problem. It also has not been shown conclusively that hand picked cotton has less dust than machine picked cotton (44).

Pre-cleaning of the incoming cotton has been shown to remove the dust. Burlington has developed a continuous steam cleaning apparatus for removal and deactivation of the dust prior to carding. Cotton is steamed for 5 minutes with low pressure steam, a time sufficient to remove the dust, but not so long that it has an adverse effect on further processing. Dust remaining in the cotton is rendered less harmful, probably because steaming has destroyed the bacteria and enzymes suspected of causing byssinosis (43).

Dust and fly are most efficiently removed at the process where they are produced, or in the case of cotton processing at the first process step. Otherwise the dust will continue to drop out at each succeeding process through spinning, until it is finally stuck into the yarn by the application of spinning oils.

Plenums are used on cards, stretch breakers, Pacific converters, etc., to remove dust and fly as they are created. Succeeding processes generally also require vacuum cleaning, especially at points where the sliver or roving goes through orifices or around turns. Exhaust air is then fed to the dust removal system. This generally consists of two or three stages, each removing successively finer particles.

With all lint and dust removal systems other than scrubbers, fire prevention is of critical importance. Filters with a UL class 1 rating do not contain combustible material, while filters with a UL class 2 rating contain combustible material in small amounts, but generally do not support combustion. Both types, however, can collect enough flammable dust to become highly flammable themselves. Lint and dust removal systems should be equipped with fire detection devices, spark arrestors, and emergency shutdown and fire extinguishing equipment.

Low energy scrubbers can be used effectively for removal of lint and coarser dust (45). Most commonly used are cyclone scrubbers and spray towers. Where the exhaust air contains entrained droplets of water or oil, scrubbers are preferred to self-cleaning filters, which would become plugged. Low energy scrubbers cannot remove fine dust of 5 microns and below, but if space has been allowed for this, a Venturi throat can be added at the inlet to remove finer particles (32). They produce humid air and must be operated with care if succeeding removal steps cannot tolerate water droplets. The use of scrubbers as devices for particulate removal is discussed in detail in Section 9.2.3.

Filters may also be used to remove lint and coarser dust. A large number of types are available, and the correct choice depends on the nature and quantity of particulate matter to be removed. Replaceable filters or filters with elements that must either be replaced or manually washed have a low installation cost, but a high operating cost in situations where large quantities of particulates must be removed. They are used chiefly for removal of small amounts of lint from an air stream, often as pre-filters prior to oil mist abatement systems, heat exchangers, or solvent recovery systems (see Sections 9.3 through 9.6). Their advantages are low initial cost, durability, and simplicity. Fiberglass or fiber elements are used for low temperature applications, while for temperatures above 250° F, as with tenter frame exhausts, steel mesh filters are preferred. When loaded, these filters are manually cleaned, and an adhesive is reapplied to improve collection efficiency.

With filters of this type, operating pressure and efficiency change during the filter life. Initially when the filter is clean, both the pressure drop across it and the operating efficiency are low. As it collects fibers and dust, the air passages become partially plugged, so that both pressure and efficiency increase toward final replacement values. When designing a system, it is safest to use the initial efficiency of a filter, but the final pressure drop. If constant airflow is required, a variable pressure across the filter can be compensated by a variable damper after the filter.

Automatic self-cleaning filters are generally used for fly removal in high fly areas, such as with exhausts from cards, breakers, etc. These are discussed in Section 9.2.2.2d.

Collected lint can be compacted for disposal or salvage as a byproduct, or it can be disposed of by incineration. In one plant (46), shearing waste is being collected using a rotary pre-filter. Blowdown from this pre-filter sends the waste to a gas fired incinerator, with only 10% of the initial exhaust air volume required for blowdown. The system was reported to have functioned with one 30 minute shutdown in one year, producing no solid waste. Installation costs were below $2.20 per initial CFM, and 1972 operating costs were below $0.70 per hour per 10,000 CFM. No solid waste was produced. Incineration is also effective in destruction of lint mixed with other liquid or gaseous pollutants. Since cost is directly proportional to the CFM of treated air, it can be prohibitively expensive if the exhaust air is not first reduced in volume by prefiltration. Incineration is discussed in greater detail in Section 9.2.1.

Fine dust that passes through a coarse filtration system can be removed by electrostatic precipitators, high efficiency air filters, Venturi scrubbers, or direct fume incinerators. These are all discussed in detail in Section 9.2. In the case of dust removal, the quantity of pollutant per CFM is generally lower than when they are used to remove oil mists. With Venturi scrubbers, potential water pollution problems are less serious than in oil mist removal. High efficiency air filters used for this purpose must be impregnated with adhesive to catch the dust. Electrostatic precipitators are the preferred method for fine dust removal because of their low operating costs and ease of maintenance. However, as explained in Section 9.2.2.3, they must be protected from entrained water droplets if a low energy scrubber is used as a pre-filter. For greater efficiency, a second stage can be added in series with the first.

TABLE 9-2

SYMBOL TABLE FOR CHAPTER 9

Symbol	Meaning
A	Heat transfer area - ft.^{2}
a	Gas-liquid interfacial area - ft.^{2}
$C_d\ (D_p)$	Proportion of particles with diameter Dp - dimensionless
B_s	Width of gravity settling chamber - ft.
C_p	Specific heat of exhaust stream after combustion - BTU/lb °F
D_b	Bubble diameter - ft.
D_d	Droplet diameter - ft.
D_p	Pollutant particle diameter - ft.
g	Gravity conversion factor - 32.17 lb. mass - ft/lb force sec^2
h	Heat transfer coefficient - BTU/hr ft^2 °F
ΔH	Pollutant heat of combustion - BTU/lb
K_m	Stokes - Cunningham correction factor - dimensionless
L_s	Gravity settling chamber length in gas flow direction - ft.
N_s	Number of compartments - gravity settling chamber
(L/G)	Liquid to gas ratio - gallons/1000 ACF
N_{SF}	Separation number - dimensionless
ΔP_i	Pressure drop - lb/ft^2
Q	Heat transfer - BTU/hr
q	Gas volumetric flow rate - ft^3/sec
ΔT	Temperature rise across a catalytic converter - °F
T_H	Heater outlet temperature - °F
t_H	Gas holdup time - sec
T_I	Heater inlet temperature - °F
V_g	Linear gas velocity ft/sec
V_l	Liquid volume - ft^3
X	Pollutant weight fraction in inlet gas - lb/lb
Vo	Pollutant - droplet relative velocity ft/sec
X_T	Droplet target width - ft
Y	Collection efficiency factor - dimensionless
ϵ	Fractional gas holdup in liquid - ft^3/ft^3
μg	Gas viscosity - lb ft/sec
η	Weight fraction of pollutant particles collected lb/lb
$\eta\ (D_p)$	Collection efficiency for particles of diameter Dp
ρ_g	Gas density - lb/ft^3
ρ_l	Liquid density lb/ft^3
ρ_p	Pollutant particle density lb/ft^3
σ	Surface tension - lb/ft
ACF	Actual Cubic Feet
CFM	Cubic Feet per Minute
CFS	Cubic Feet per Second
SCF	Standard Cubic Feet (at 32°F, 1 atm)
SCFM	Standard Cubic Feet per Minute
HP	Horsepower
U_{gt}	Superficial gas velocity - ft/sec
U_r	Terminal bubble rise velocity ft/sec (.87 ft/sec for all practical purposes)

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CHAPTER 10

PERSONNEL REQUIREMENTS

10.1 Introduction

This chapter contains information relating to the staffing requirements associated with textile wastewater treatment facilities. Manhour estimates have been prepared for each EPA subcategory according to plant wastewater flows assumed for small, medium, and large textile production facilities. Plant production and water use are taken from the National Commission on Water Quality Report (1). Personnel requirements are based upon "average" plant conditions assuming the following:

- Standard plant layout
- Commonly used equipment in relatively new and well cared for condition
- Moderate climate
- Certified plant operator with average productivity
- Plant wastewater flow not in excess of design flow

10.2 Adjustment Factors

A number of local conditions tend to affect average situations presented in the tabulations in this chapter. Values given to these adjustment factors are presented in the EPA publication entitled: *Estimating Staffing for Municipal Wastewater Facilities* (2). Local conditions are described as follows:

10.2.1 Plant Layout

Unusual layout conditions will affect operating and maintenance staffing because of the time required to walk from one piece of equipment to another.

10.2.2 Unit Processes

A plant with multiple process equipment units of the same type which come from different manufacturers is less efficient to maintain than a plant where all or most of the equipment of the same type is from the same manufacturer. A plant with non-standard process equipment will also be less efficient to maintain and operate than a plant with standard equipment.

10.2.3 Level of Treatment

Where a level of treatment is more stringent than BPT and requires more than the treatment models shown in Chapter 7, adjustment of manhours is necessary.

10.2.4 Productivity of Labor

The productivity for labor assumes 6.5 hours of productive work per man per day which amounts to 1,500 hours per year as the normal level of labor productivity.

10.2.5 Climate

Where winters are severe, maintenance manhours should increase.

10.2.6 Training

The manhours required are based on plant personnel which have the uniformly high level of training indicated by certification, but do not have the benefit of a continuing education program. The importance of competent plant operators cannot be overemphasized.

10.2.7 Off Plant Laboratory Work

Where laboratory work is done by outside contractors, laboratory staffing needs would be reduced. In the small plant, laboratory work may be done by the lab technician or chemist serving in textile operation plant.

10.2.9 Off Plant Maintenance

Ground and building maintenance for small plants may be done by the manufacturing plant personnel. Instrument and control system maintenance which requires special skill may be contracted by outside contractors. Some maintenance that cannot be scheduled, such as electric rewinding or mechanism repair, may be done by outside personnel on a job-by-job basis.

10.2.10 Age and Conditions of Equipment

Maintenance workload should be increased if plant equipment is old or improperly cared for.

10.2.11 Safety

From a safety standpoint it may be advisable to have a minimum of 2 men working at the plant facility during any shift.

10.3 Estimating Annual Manhours

Manhour estimates have been made for operation, maintenance and laboratory functions required for an effective treatment program. Tables 10-1 through 10-7 illustrate annual manhours required for each function associated with meeting BPT.

It should be noted that supervisory manhours are included in annual operation and that yardwork is included in maintenance manhours. Clerical manhours are not included as it is assumed manufacturing plant personnel will perform this function. The 1500 manhours per year per man assumes 5-day work week and an average of 29 days for holidays and vacation. The tables also present the total number of men required. It is, of course, possible for one man to perform more than one function.

TABLE 10-1

CATEGORY 1
WOOL SCOURING

MILL SIZE	FLOW	MANHOURS FOR BPT			TOTAL MAN REQUIREMENTS
(lb./day)	MGD	Operation	Maintenance	Lab	BPT
30,000	0.13	1,400	1,300	300	2.0
80,000	0.344	1,776	1,672	350	2.5
150,000	0.645	2,560	2,079	550	3.5

TABLE 10-2

CATEGORY 2
WOOL FINISHING

MILL SIZE	FLOW	MANHOURS FOR BPT			TOTAL MAN REQUIREMENT
(lb./day)	MGD	Operation	Maintenance	Lab	BPT
5,000	0.2	900	950	240	1.5
20,000	0.8	2,150	1,815	500	3.0
135,000	5.4	6,450	3,840	1,600	8.0

TABLE 10-3

CATEGORY 3
DRY PROCESSING

MILL SIZE	FLOW	MANHOURS FOR BPT			TOTAL MAN REQUIREMENT
(lb./day)	MGD	Operation	Maintenance	Lab	BPT
20,000	0.03	700	800	180	1.0
60,000	0.16	970	1,035	200	1.5
140,000	0.66	1,860	1,752	480	3.0

TABLE 10-4
CATEGORY 4
WOVEN FABRIC FINISHING

MILL SIZE (lb./day)	FLOW MGD	MANHOURS FOR BPT Operation	Maintenance	Lab	TOTAL MAN REQUIREMENT BPT
40,000	0.54	1,775	1,345	420	2.0
180,000	2.43	3,840	2,860	1,000	5.0
500,000	6.75	7,890	4,990	1,800	10.0

TABLE 10-5
CATEGORY 5
KNIT FABRIC FINISHING

MILL SIZE (lb./day)	FLOW MGD	MANHOURS FOR BPT Operation	Maintenance	Lab	TOTAL MAN REQUIREMENT BPT
20,000	0.36	1,240	1,190	350	2.0
60,000	1.08	2,400	2,040	650	3.5
110,000	1.98	3,270	2,600	900	4.5

TABLE 10-6
CATEGORY 6
INTEGRATED CARPET MILL

MILL SIZE (lb./day)	FLOW MGD	MANHOURS FOR BPT Operation	Maintenance	Lab	TOTAL MAN REQUIREMENT BPT
20,000	0.166	740	800	230	1.0
60,000	0.498	1,190	1,190	400	2.0
100,000	0.83	1,730	1,640	540	2.5

TABLE 10-7
CATEGORY 7
STOCK AND YARN DYEING AND FINISHING

MILL SIZE (lb./day)	FLOW MGD	MANHOURS FOR BPT Operation	Maintenance	Lab	TOTAL MAN REQUIREMENT BPT
20,000	0.4	1,130	1,090	380	2.0
65,000	1.2	2,200	1,790	650	3.0
130,000	2.4	3,390	2,525	1,000	5.0

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CHAPTER 11

DESIGN DATA CHECKLIST

11.1 General Process Data

Company Name: ____________________

Plant Name: ____________________

Address: ____________________

____

____

Telephone No: ____________________

Contacts: ____________________ Plant Engr.

____________________ Plant Mgr.

____________________ Other

____

A. MANUFACTURING

1. *Fibers Used:*

____Wool
____Cotton
____Acetate
____Acrylic
____Modacrylic
____Nylon
____Polyester
____Rayon
____Other

2. *Production Processes:*

Slashing____

Weaving:
- ____Broad
- ____Narrow

Non Woven:
- ____Chem. Bond
- ____Mech. Bond
- ____Therm. Bond

Tufting____

Knitting:
- ____Circular
- ____Warp

Flocking____

Preparation:
- ____Bleaching
- ____Washing
- ____Scouring
- ____Carbonizing
- ____Mercerizing

Printing____

Finishing:
- ____ Softening
- ____ Waterproof
- ____ Fireproof
- ____ Tentering
- ____ Mildew Proof
- ____ Wash & Wear
- ____ Perm. Press
- ____ Other

Dyeing:

___ Yarn (space or skein)
___ Piece
___ Package

3. *End Products:*

Greige Goods.	Finished Fabrics:
___ Knitted	___ Knitted
___ Tufted Carpets	___ Tufted Carpets
___ Woven	___ Woven
Dyed Yarns ___	Other ___

4. *Volume Produced:* ________ lb/week avg.
________ lb/week max.

5. *Operation:* ________ hrs/wk
________ shifts/day

6. *Number of Employees:* ____

7. *Process Water Use:* ______ gal/day (avg.)

8. *All Other Water Use:* ______ gal/day (avg.)

9. *Intake Water Source:*

___ Municipal
___ Surface
___ Subsurface
___ Other

B. CHEMICAL AND DYES USED

1. *Size:*

___ %Starch
___ %PVA
___ %CMC
___ %Other

2. *Desizing:*

____ Sulfuric Acid
____ Enzymes
____ Other

3. *Scouring or Washing:*

____ Soap
____ Detergent
____ Caustic Soda
____ Soda Ash
____ Other

4. *Bleaching:*

____ Sulfur Dioxide
____ Sodium Hypochlorite
____ Sodium Chlorite
____ Hydrogen Peroxide
____ Other

5. *Fulling:*

____ Acid
____ Alkali
____ Other

6. *Neutralizing:*

____ Sulfuric Acid
____ Other

7. *Dyeing:*

____ Vat
____ Direct
____ Disperse
____ Sulfur
____ Acid
____ Cationic
____ Developed
____ Reactive
____ Other

8. *Finishing:*

____ Starch
____ Dextrin
____ Wax
____ Tallow
____ Oil
____ Clay
____ Talc
____ Lacquers
____ Sulfonated Compounds
____ Ammonium Salts
____ Cellulosic Compounds
____ Special Finishes
____ Detergents
____ Soaps
____ Other

C. WASTEWATER CHARACTERISTICS

1. *Flow:*

Average ______ gal./day
Maximum ______ gal./day

2. *Waste Components:*

___ % Industrial
___ % Sanitary
___ % Other

3. *Effluent Quality*

BOD	___ mg/l	Temperature	___ °F
COD	___ mg/l	Oil & Grease	___ mg/l
TSS	___ mg/l	Nitrogen	___ mg/l
Chromium	___ mg/l	Phosphorus	___ mg/l
Phenol	___ mg/l	Alkalinity	___ mg/l
Sulfide	___ mg/l	Other Metals	___ mg/l
Color	___ ADMI	Fecal Coliform	___ MPN
pH	___ Units		

4. *Available Discharge Points:*

Receiving Stream ___
Municipal Sewer ___
Other ___

D. EXISTING TREATMENT FACILITIES

1. *Physical Pretreatment:*

___ Equalization
___ Screening
___ Pre-aeration
___ Sedimentation
___ Flotation
___ Temperature Control
___ Other (describe)
____

2. *Chemical Pretreatment:*

___ Neutralization
___ Primary Chemical Coagulation
___ Chemical Treatment
___ Odor Control
___ Nutrient Addition
___ Other (describe)
____

3. *Biological Treatment:*

___ Stabilization Basins
___ Activated Sludge
___ Trickling Filter
___ Aerated Lagoon
___ Anaerobic Contact (6 to 12 hours)
___ Anerobic Pond (3 to 30 day)
___ Denitrification
___ Aerobic or Anaerobic-Digestion of Solids
___ Other (describe)
____

4. *Sludge Handling:*

___ Thickening
___ Lagooning or Drying Bed
___ Centrifugation
___ Vacuum Filtration
___ Filter Pressurization
___ Dry Combustion
___ Wet Combustion
___ Land Disposal
___ Sea Disposal
___ Other (describe)
____

5. *Terminal Secondary Treatment:*

___ Biological Sedimentation
___ Final Chemical Coagulation Sedimentation
___ Sand Filtration
___ Diatomite Filtration
___ Chlorination
___ Other (describe)
____

6. *Temperature Change Processes:*

___ Evaporation
___ Freezing
___ Distillation
___ Eutectic Freezing
___ Wet Oxidation
___ Process Residue, Handling & Disposal
___ Other (describe)
____

7. *Miscellaneous:*

___ Absorption
___ Electrodialysis
___ Ion Exchange
___ Solvent Extraction
___ Reverse Osmosis
___ Foaming
___ Electrochemical Treatment
___ Other (describe)
____

8. *Treated Wastewater Disposal:*

___ Controlled Discharge
___ Surface Storage and Evaporation
___ Deepwell Disposal
___ Surface (spray) irrigation
___ Ocean Disposal
___ Surface Discharge
___ Other (describe)
____

DESIGN PARAMETER

CHECKLIST

11.2 Treatment Unit Design

1. *Influent Design Conditions:*

Wastewater Flow
Average ____mgd
Maximum ____mgd
Minimum ____mgd
BOD Loading
Average ____lb/day
90 Percentile ____lb/day
Wastewater Temp. ____°F

2. *Effluent Design Conditions:*

Wastewater Flow
Average ____mgd
Maximum ____mgd
BOD Loading
Average Total ____lb/day
Maximum Total ____lb/day
VSS Concentration ____mg/1

3. *Screening:*

Flow Rate _____gpm
Spacing _____in. & mesh
Slope _____degrees
Velocity _____fps

4. *Clarification:*

Overflow Rate _____gpd/ft^2
Detention Time _____Hours
Depth _____ft.
Weir Rate _____gal/day/ft.

5. *Multi-Media Filtration:*

Hydraulic Load _____gpm/ft^2
Solids Load _____lb/day/ft^2
Depth _____inches
Filter Run Time _____hours

6. *Flotation:*

Hydraulic Loading _____gpm/ft^2
Operating Pressure _____psig
Gas to Solids _____weight ratio
Pressurization Type _____recycle/partial/total

7. *Equalization:*

Detention Time _____hours
Volume _____gallons
Mixing Required _____HP/1000 gal
Depth _____ft.

8. *Neutralization:*

Detention Time _____minutes
Agitator Speed _____fps
Chemicals Used _____
Feed Range _____

9. *Aerated Lagoons:*

Detention Time ____ days

Depth ____ feet

Oxygen Utilization ____ lb. BOD/day/HP

10. *Extended Aeration:*

Detention Time ____ days

Depth ____ ft.

Recirculation ____ %

Organic Loading (F/M) ____ $\frac{\text{lb BOD/day}}{\text{lb MLVSS}}$

MLVSS Concentration ____ mg/1

Air Requirements ____ HP of ft^3/lb BOD/day

Sludge Volume Index ____ ml/g settled MLSS

11. *Trickling Filter:*

(Synthetic Media)

BOD Loading ____ lb BOD/1000 ft^3/day

Recirculation Rate ____ ratio

Filter Bed Depth ____ ft.

12. *Activated Carbon Catalyst:*

Carbon Dosage ____ mg/1

Resident Time ____ hours

Regenerate/Throwaway ____

13. *Chemical Coagulation:*

Rapid Mixing

Detention Time ____ minutes

Depth ____ ft.

Mixing Power ____ HP/1000 ft^3

Mixing Speed ____ rpm

Chemical Requirements

Coagulant ____ mg/1

Polymer ____ mg/1

Flocculation
  Detention Time ____ minutes
  Depth ____ feet
  Mixing Power ____ HP/1000 ft^3
  Mixing Speed ____ rpm
Clarification
  Overflow Rate ____ gpd/ft^2
  Depth ____ ft.

14. *Polishing Ponds:*
  Depth ____ ft.
  Loading Rate ____ lb BOD/acre/day
  Detention Time ____ days

15. *Chrome Removal:*
  Reduction pH ____ units
  Precipitation pH ____ units
  Flocculation Time ____ minutes
  Clarifier Overflow Rate ____ gpd/ft^2
  Clarifier Depth ____ ft.
  Sludge Concentration ____ % weight

16. *Activated Carbon Adsorption:*
  Flow Rate ____ gpm/ft^2
  Carbon Size ____ mesh
  Backwash Rate ____ gpm/ft^2
  Reactivation
    Temperature ____ °F
    Furnace Loading ____ $lb/ft^2/day$
    Carbon Loss ____ %

17. *Synthetic Resin Adsorption:*
  Hydraulic Loading ____ gpm/ft^2
  Regeneration Time ____ days
  Backwash Rate ____ gpm

18. *Hyperfiltration:*

Membrane Type _____
Pre-Filter Size _____ microns
pH _____ units
Temperature _____ °F
Pressure _____ psi

19. *Aerobic Digester:*

Detention Time _____ days
VSS Loading _____ lb/ft^3/day
Air Requirements _____ hp or cfm vol.
Temperature _____ ° F
Tank Depth _____ ft.
Volatile Solids Reduction _____ %

20. *Gravity Thickener:*

Influent Solids Concentration _____ %
Solids Flux Rate _____ lb. ss/ft^2-day
Underflow SS Concentration _____ %
Overflow Rate _____ gal/day/ft^2

21. *Sludge Drying Beds:*

Solids Loading _____ lb/sq. ft./yr.
Media Size _____ mm
Bed Depth _____ inches

22. *Spray Irrigation:*

Application Rate _____ in/wk.
Spray Schedule _____ spray-rest

23. *Chlorination:*

Chlorine Dosage _____ mg/1
Contact Time _____ min.
Form of Chlorine _____

24. *Ozonation:*

Ozone Dosage ____ mg/l

Contact Time ____ min.

Form of Ozone ____

APPENDIX A

GLOSSARY

Accelerators	Chemical used to increase color development in textile dyeing operation or to promote cross-linking between two chemicals on a fiber or a chemical and a fiber.
Acetate	A manufactured fiber made from cellulose acetate.
Acetic Acid	A weak acid used in wool, nylon, polyester, etc., dyeing. Normally can be replaced by ammonium sulfate.
ACFM	Actual cubic feet per minute. Air flow at the actual operating condition of temperature and pressure.
Acrylic	A manufactured fiber in which the fiberforming substance is any long chain synthetic polymer composed of at least 85% by weight of acrylonitrile units. Made in both filament and staple form.
Acid Dye	A type of dye commonly used to color wool and nylon but may be used on other fibers.
ADMI Color	Analytical method of evaluating color, developed by the American Dye Manufacturer's Institute.
Adsorption	The adhesion of an extremely thin layer of molecules to the surfaces of solids or liquids with which they are in contact.
Aerobic	Living or active only in the presence of oxygen.
Ageing	Fabrics are aged by heat, acid or some other means.
Agglomeration	A phenomenon where particles mass together.
Alkaline	Presence of the hydroxides, carbonates, and bicarbonate of elements, such as calcium, magnesium, sodium, potassium; or of ammonia. Alkaline pH ranges from 7.1 to 14.

Ammonium Sulfate	Acid forming salt used in wool stock dyeing.
Anaerobic	Living or active only in the absence of free oxygen.
Ash	The combustible solid matter in fuel or refuse.
Azoic	A type of dye used to color cotton, rayon, polyester and cotton/polyester blends, but not commonly used.
Basic Dye	Also known as cationic dye. It is used to color synthetic fiber or cotton/polyester blends.
Beam	Any of various machines for dyeing which use a perforated beam through which the dye bath is circulated.
Beck	Any of various machines for scouring (cleaning), dyeing, etc., goods while in the form of rope or endless belt. A roller gradually moves the cloth through the bath in a slack condition.
Bleaching	The treatment of textile fibers, yarns or cloth to destroy the natural coloring matter and leave the material white. Hydrogen peroxide is a widely used bleaching agent.
Blend	The combination of two or more types of fibers and/or colors in one yarn.
Blowdown	Periodic or continuous draw-off of a mixture from a system to prevent buildup of contaminants.
BOD	Biochemical oxygen demand. A method of measuring rate of oxygen usage due to biological oxidation. A BOD_5 of 1000 mg/liter means that a sample (1 liter) used 1000 mg of oxygen in 5 days.
Calender	A machine using heavy rollers to impart a variety of effects in the finishing of cloths, particularly cotton and rayon.
Carbonizing	An acid treatment of wool to remove vegetable matter (burrs, straw, etc.) followed by heat.

Carbonizing	A phenomenon where a carbonaceous material is decomposed leaving a residue of essentially black carbon, e.g. soot.
Carding	Fibers are separated and aligned in a thin web, then condensed into a continuous, untwisted strand called a "sliver".
Carrier	A water-insoluble organic compound which accelerates the absorption of dyes by a fiber. Disperse dyes used with polyester most commonly utilize carriers.
Catalytic Incinerators	Incinerators for gaseous materials which utilize a catalyst to reduce the operation temperature.
Cellulose	Major component of cotton and rayon. Also used as the base for acetate fiber.
CMC	Carboxmethyl cellulose. Synthetic size used in sizing process of cotton fabric manufacturing.
COD	Chemical oxygen demand. The amount of oxygen required for the chemical oxidation of organics in a liquid.
Combing	A method removing short fibers and foreign matter from cotton or wool stock by processing it through a series of needles (or combs).
Compacting	A mechanical compressive shrinkage operation.
Decating	Using a combination of steam and pressure to give a soft hand and feel to the fabric.
Denitrification	The reduction of nitrate to nitrogen gas by denitrifying organisms.
Desize	A process for removing size material from greige (gray) goods in preparation for bleaching, dyeing, etc.
Desuinting	Removing of natural impurities and dirt in wool fiber.

Developers	Chemicals used in dyeing process, whose color is developed by reaction on cotton.
Direct Dye	Anionic, water soluble dye used primarily for dyeing full shade ranges on cotton and rayon.
Disperse Dye	Water insoluble dye used to color several synthetic fibers. Applied as a fine dispersion using a carrier. On cloth, padded dye may be baked on or "thermofixed".
Dissolved Oxygen	Oxygen in water required for the respiration of aerobic microorganisms.
Drawing	Straightening and paralleling the fibers after combing or carding.
Dry Cleaning	Cleaning of dyed yarn or fabric with a solvent rather than scouring in a water solution.
Dyeing Jigs	Open width on the dyeing machine. Cloth moves from one roll to another through the dye liquor until the desired shade is obtained.
Electrostatic Precipitation	A process in which particles are collected by means of electric charge.
Emission	In environmental work, a reference to gaseous discharges to the atmosphere as opposed to effluent which refers to liquid and solid discharges.
Eutrophication	Process whereby lakes or streams become enriched with biological nutrients, usually nitrogen and phosphorus.
Extracting	Water is removed by centrifuge prior to slitting.
F/M	Food to microorganism ratio.
Fecal Coliform	An indicator organism for evaluating the micro-biological suitability of the water.

Felt	A fabric made with no systems of threads but constructed by interlocking of fibers in the fabric. Wool and cotton are the most common fibers used.
Fiber Reactive	A type of dye used to color cotton, nylon and polyester/cotton blend. This dye gives bright shades, good all around fastness and easy application.
Filament	A man-made continuous strand of yarn of near infinite length.
Fleece	Quantity of wool cut from individual sheep at shearing time.
Floc	An agglomeration of finely divided or colloidal particles.
Fly Ash	Fine particles of ash carried by the products of combustion.
Framing	Drying or impregnating of fabric with a resin or starch and drying at the correct width.
Fulling	A shrinking process for wool utilizing moisture, heat, friction and pressure. Also, known as felting or milling.
Gilling	The operation in wool yarn manufacturing to straighten and parallel the fibers.
Grain	A unit of weight measure (gr): 7,000 gr = 1 lb.
Greige	Fabrics in unbleached, undyed state before finishing. In U.S. "gray goods" or "grey goods".
Hank	A definite length of material which varies for different fibers, basically the number of yards equivalent to one pound.
Heat Pipe	A long cylindrical sealed heat transfer element that operates by means of an internal flowing medium.
Impaction	A phenomenon wherein particles are stopped or collected by collision with a material or medium.

Incineration	With reference to gaseous materials, an abatement technique where the stream is heated to a specified temperature for a specified length of time to enable combustion of the pollutants. It is commonly 1,400° F for one half second.
J-Box	A J-shaped device often used in bleaching continuously. Cloth is stored in the J-shape arrangement for a required dwell time at a designated temperature.
Jet Dyeing	A tubular machine utilizing water jets to circulate fabric in a dye bath.
Jig	An open vat which passes full width cloth from a roller through dye liquor and then onto another roller. The operation is repeated until the desired shade is obtained.
Jute	Coarse, brown fiber from the stalk of a bast plant grown in India. Used mainly for burlap, cordage, and as a backing for rugs and carpets.
Kier	A piece of equipment in which cotton is boiled with dilute caustic soda to remove impurities. Also, designates a pressure vessel used for the dyeing of yarn and fabric.
Knitting	Process of making fabric by interlocking series of loops of one or more yarns. Types are: jersey (circular knits), tricots (warp knits), double knits.
Loading	In air and water pollution, a term generally referring to the weight rate of an emission as opposed to concentration.
Lower Explosive Limit (LEL)	The lowest concentration of a dust, gas or vapor in which flame propagation can occur.
Mercerizing	A process given to cotton yarns and fabrics to increase luster, improve strength and dyeability. Treatment consists of impregnating fabrics with cold concentrated sodium hydroxide solution.

Metalized Dye	Two acid dyes (anionic, water soluble) joined together to make a larger molecule which has greater light and wet fastness. Used primarily for dyeing nylon and wool where high fastness is required.
Milling	See *Fulling*.
Mist Eliminator	A device for removing mist from a gas stream.
MLSS	Mixed Liquor Suspended Solids. The concentration of suspended solids carried in the aeration basin of an activated sludge process.
MPN	Most probable number. Expressed as density of organisms per 100 ml.
Modacrylics	Generic name established by the Federal Trade Commission for a "manufactured fiber in which the fiber-forming substance is any longchain synthetic polymer composed of less than 85% but at least 35% by weight of acrylonitrile units".
Napthol	An azo dye whose color is formed by coupling with a naphthol. Used chiefly on cotton.
Nip	A squeeze performed by two rolls under pressure.
Nitrified Effluent	Effluent in which ammonia is converted to nitrate or nitrite.
Nutrient	Any substance assimilated by an organism which promotes growth and replacement of cellular constituents.
Nylon	Generic name for "a manufactured fiber in which the fiber forming substance is any long-chain synthetic polyamide in which less than 85% of the amide in linkages are attached to two aromatic rings".
Oxidizing Agents	Any substance which can receive electrons and thereby cause some other chemical to increase in positive charge.

Package Dyeing	The dyeing of yarns in the form of a package of various kinds and sizes. Packages wound onto perforated tubes or springs are placed on perforated spindles in a closed vat and the dye bath is circulated in and out of the package.
Pad	A machine for impregnating fabrics with chemicals. It consists essentially of a trough followed by two or more pairs of squeeze rolls.
Paddle Machine	A dye vat that uses paddle to convey the goods through the dye bath.
Particulate Matter	Any material except uncombined water which exists in a finely divided form as a liquid or solid.
pH	Unit used to describe acidity or alkalinity. pH 7 is neutral; above 7 is alkaline and below 7 is acidic.
Phenols	Organic compounds which cause taste problems in water particularly when the water is chlorinated.
Picking	The process of yarn manufacturing in which cotton is opened, cleaned and rolled into a lap.
Pierce Dyeing	A method used to dye fabrics a solid color. May be done continuously, jig, pad, beck, etc.
Plume Opacity	The resistance of air emission material to passage of visible light.
Polyester	A manufactured fiber in which the fiberforming substance is any long-chain synthetic polymer composed of at least 85% by weight of an ester of dihydric alcohol and terephthalic acid.
Printing	Process of producing designs of one or more colors on a fabric. There are several methods, such as roller, block, screen, etc., and several color techniques, such as direct, discharge and resist.
PVA	Polyvinyl Alcohol. Synthetic size used in sizing process in cotton fabric manufacturing.

Quilling	Yarn which is to go on the loom as filling is wound onto a quill which is placed in the shuttle at the loom.
Raising	A woolen finishing process designed to create a nap on the surface of the cloth.
Rayon	A generic name for man-made fibers, mono-filaments and continuous filaments, made from regenerated cellulose. Fibers produced by both viscose and cuprammonium process are classified as rayon.
Receiving Water	Surface waters which assimilate effluent discharge.
Recuperator	An enclosed wash box utilizing low pressure steam. Most often found on a mercerizing range.
Reducing Agent	Any substance that can give electrons.
Resin	A chemical finish used to impart a property desired in a fabric, such as water repellency or hand, etc.
Retardants	Chemicals applied topically to fabrics or in-situ to fibers to retard burning, etc.
Rope Soaper	A piece of equipment used for scouring fabrics to remove impurities, processing oils, excess dye etc.
Sanforizing	A mechanical shrinkage of the fabric.
Saturator	A box used to impregnate fabric with chemicals in a continuous range.
SCFM	Standard cubic feet per minute. Air flow corrected to predefined standard conditions of temperature and pressure, generally 32° F and one atmosphere in air pollution work.
Scouring	Removal of foreign components from textiles. Normal scouring materials are alkalies (e.g. soda ash) or trisodium phosphate, frequently used in the presence of a surfactant. Textile materials are sometimes scoured by use of a solvent.

Scray	A device used primarily to provide some flexibility or dwell time in continuous range.
Scrubber	In air pollution, a device in which a contaminated stream is contacted with a liquid to reduce contaminant emission.
Septic	Causing anaerobic biological activities due to insufficient oxygen present in wastewaters.
Singeing	Cloth passes across an open gas flame at a high rate of speed to burn off the loose surface fibers.
Sizing	Applying starch, PVA or CMC to warp yarns to minimize abrasion during weaving.
Slashing	A number of beams from the warper are placed into a creel, run through a size solution and dried on a series of drying cans.
Souring	Usually a cotton treatment using a weak acid solution to neutralize excess amounts of alkali.
Spinning	A process by which a large strand of fibers is drawn out to a small strand and converted into a yarn. After drawing out (or drafting), twist is inserted, and the resulting yarn is wound into a bobbin.
SS	Suspended Solids. Solids that either float on the surface of or are in suspension in water.
Starch	Organic polymer material used as a size; highly biodegradable.
Stiochiometric	A reference to the combining weights of the elements in a chemical reaction.
Stripping Agents	Chemical used in textile processing to take off impurities covering the fabric.
Suint	Dried sheep perspiration.

Sulfur Dyes	A class of dyes which dissolve in an aqueous sodium sulfide forming product with a marked affinity for cotton; the dyes are regenerated by air oxidation.
Tentering	Open width fabric is run through a tenter frame which holds it at the desired width, fabric is dried and wound onto a roll.
Textured	Bulked yarns that have greater volume and surface interest than conventional yarn of same fiber.
Thermosol (DuPont)	A continuous dyeing process where the fabric is padded with dye, dried and the dye is fixed at temperatures between 180-220° C in an oven.
Top	A continuous untwisted strand or sliver of wool fibers wound into a large ball.
Tufted Yarn	These are very coarse yarns, usually plied, designed for the tufting trade. Most tufting yarns are made from nylon, acrylic or polyester fiber.
TSS	Total suspended solids. Amount of solids separated by filtration of a sample of wastewater.
Unrolling	Knitted fabric is unrolled into a box or basket in preparation for scouring.
Vat Dye	A type of insoluble dye applied from a liquor containing alkali and a powerful reducing agent, generally hydrosulfite. The dye then becomes soluble and completely permeates the cotton fiber. It is then oxidized and again becomes insoluble.
Venturi Scrubber	A scrubber in which gas velocity is increased in the presence of a liquid due to a decrease in cross section area of the duct causing particulate matter to be captured by impaction into the liquid.
VSS	Volatile suspended solids.

Warp	Set of lengthwise yarns in a loom through which the crosswise filling yarns (weft) are interlaced. Sometimes called "ends".
Weaving	The process of manufacturing fabric by interlacing a series of warp yarns with filling yarns at right angles.
Winch	See (Beck).
Winding	Yarn is wound onto one of several different types of large packages and most of the slubs or thick places are taken out.
Worsted	A wool fabric which uses finer grades of wool with finer yarns and higher weaving constructions than a woolen fabric.
Yarn	An assemblage of fibers or filaments, either manufactured or natural, twisted or laid together so as to form a continuous strand which can be used in weaving, knitting or otherwise made into a textile material.

APPENDIX B

METRIC CONVERSION CHART

Multiply	*By*	*To Get*
Inches	2.54	Centimeters
Feet	0.3048	Meters
Square Feet	0.0929	Square Meters
Cubic Feet	0.0283	Cubic Meters
Pounds	0.454	Kilograms
Gallons	3.79	Liters
Gallons/Minute	5.458	Cubic Meters/Day
Feet/Second	0.305	Meters/Second
Fahrenheit	0.555 (°F-32)	Centrigrade
Acre	0.405	Hectares
BTU	0.252	Kilogram — Calories
Horsepower	0.7457	Kilowatts

APPENDIX C

DEFINITIONS OF MANUFACTURING OPERATION

1. *Commission Scouring* shall mean the scouring of wool, 50% or more of which is owned by others, in mills that are 51% or more independent (i.e. only a minority ownership by company (ies) with greige or integrated operations); the mills must process 20% or more of their commissioned production through batch, noncontinuous processing operations.

2. *Commission finishing* shall mean the finishing of textile materials 50% or more which are owned by others, in mills that are 51% or more independent (i.e. only a minority ownership by company (ies) with greige or integrated operations); the mills must process 20% or more of their commissioned productions through batch, noncontinuous processing operation with 50% or more of their commissioned orders processed in 5,000 yards or smaller lots.

3. *Simple manufacturing* shall mean all the following processes: Desizing, fiber preparation and dyeing.

4. *Complex manufacturing* shall mean simple manufacturing processes plus any additional manufacturing operations such as printing, water proofing, or applying stain resistance or other functional fabric finishes.

5. *Complex manufacturing* shall mean fiber preparation, dyeing, carpet backing plus additional operations such as printing or dyeing and printing.

APPENDIX D

BOD OF TEXTILE CHEMICALS

An abbreviated list of the 5-day BOD of Textile Chemicals. These values are based on the weight of chemicals as received, i.e., if a chemical shows a BOD of 140%, then 1 pound will yield 1.4 pounds of BOD. The exception to this is reference 5 where the BOD is based on the dry weight of chemicals.

Name	*Ref.*	*Composition: use*	*BOD percent*
Acetic Acid, 56%	(2)	CH_3COOH; dyeing, scouring	33,36
Acetone	(2)	CH_3COCH_3; solvent	122*
Aerotex Resin M-3	(2)	Melamine-formaldehyde; finishing	23.
Aerotex Syrup 250 Conc.	(2)	Urea-formaldehyde condensate; durable finishes	5.
Ahcovel G	(2)	Fatty carbamide; cation-active sustantive softening agent	2.
Alkamine C	(5)	Fatty amide condensate	45.
Avcosol 20	(1)	Waxy sorvital ester; sizes, spinning and carding oil	42.
Avitex R	(2)	High alkylamine; special finishing agent	5.
B–2 Gum	(2)	Starch dextrins; printing ink, size	61.
Brytex Gum No. 745	(2)	Starch: printing ink, sizes	61.
Carbonwax 200	(5)	Polyethylene glycol	2.
Cetosol SF	(2)	Synthetic resin; finishing	24.
C-Prosan	(6)	Synthetic wax	129.
Duponol C	(2)	Lauryl sulfate: detergent and wetting agent	125.
Duponol RA	(7)	Surface active agent	13.
Dyes			
Alizarine Cyanine Green GHN Conc. CF	(2)	Acid dye	Near 0**.
Calcogene Black GXCF Conc	(2)	Sulfur dye	10.
Celliton Fast Blue AF 100%	(2)	Acetate color	3.
Erie Brilliant Black S 150%	(2)	Direct dye	8.
Fast Red Salt 3GL	(2)	Insoluble azo compound	2.
Khaki carbanthrene 2G	(2)	Vat dye	0.
Naphthol AS–BR	(2)	Prepare	10.
Nyaform Blue 2B	(2)	Direct dye (formaldehyde after treatment)	Near 0**
Mixture of 18 dyes	(2)	Dyes	7.
Dypensol SED	(1)	Polyhydric alcohol and cresylates; mercerizing assistant	39.
Elvacet	(4)	Polyvinyl acetate water emulsions	1.
Elvanol 72-60	(2)	Polyvinyl alcohol; finishing agent, sizing compound	1.
Ethanol	(2)(4)	C_2H_5OH; solvent	93*, 125.
Ethyl Acetate	(2)	$C_2H_5CO_2CH_3$; solvent	66*.
Experimental 377	(6)	Detergent	12.
Formaldehyde, 37%	(2)	HCHO: shrinkproofing, creaseproofing, modifying dyeing characteristics	37.
Formic Acid, 85%	(2)	HCOOH; scouring	2.
Foryl R 333	(6)	Scouring	66†.
Globe Easy Flow Starch	(6)	Size	65.
Gelatin	(1)	Gelatin; sizes	100.
Glue	(1)	Glue, sizes	66.

70% Hydroxyacetic acid	(6)	$HOCH_2COOH$	7.
Hydroxy Ammonium sulfate	(4)	$(NH_2OH_2SO_4$	4.
Igepal	(2)	Polymerized ethylene oxide alkyl phenol condensation product; detergent, wetting agent, emulsifying, dispersing	4.
Ivory Snow	(1)(4)	Sodium salt of fatty acid	122,141.
Kyro EO	(1)	Polyethylene oxide condensate; synthetic detergent	0.
Lanalbine	(6)	Protein hydrolyzate; wool protective agent	13.
Monochlorobenzene	(2)	C_6H_5C1; swelling agent in dyeing of Dacron, dyeing assistant	3.
Morningstar Starch	(2)	Starch; sizes, spinning and carding oils	47.
Morpholine	(2)	$O: (CH_2CH_2): NH$; dye solvent, emulsifying agent, corrosion inhibitor	2*.
Nacconol NR	(2)	Sodium alkylarylsulfonate; detergent	0,4.
Neutronyx 600	(2)	Aromatic polyglycol ether; scouring agent for all fibers	0.
Nopco 1111	(1)	Sulfonated coconut oil; emulsifying agent	96.
Nopcolube 55	(6)	Synthetic wax for warp sizing	80.
Norane W–1	(1)	Wax emulsion; water repellent with Norane W–2	70.
Orvus EC Paste	(3)	Mod. Sodium alkyl sulfate type	23.
Oxalic Acid	(2)	$H_2C_20_4\ 2H_20$; rust removal	14.
Oxytrol	(5)	Highly substituted starch	15.
Paralube 20 (Tween 20)	(6)	Anti-static	33.
Parval	(2)	Fatty amine condensate plus amine soap; scouring, fulling.	5.
Penetrant GW	(6)	Leveling agent	14.
Peter Copper Size	(1)	Glue; sizes, spinning and carding oils	118.
Phenol	(1)	C_6H_5OH; dyeing	200.
Picking Oil	(1)	Sizes, spinning and carding oils	13.
Product BCO	(7)	Surface active agent	3.
Rapidase M	(2)	Amylolytic and proteolytic enzymes, desizing agent	4.
Red Oil	(2)	Sulfonated castor oil, soapmaking, carding	68+.
Resloom NP Special	(2)	Mela[illegible]formaldehyde condensate; finishing	11,14.
Rhonite 313	(2)	Urea-for[illegible]aldehyde resin; finishing	11.
Rhonite R–1	(2)	Modified urea-formaldehyde resin; finishing	7.
Salicylic Acid	(1)	$C_6H_4(OH)\ COOH$; dyeing	141.
Soap, Nonpareil	(2)	Fatty acid soap; scouring, fulling washing	140.
Sodium Alginate	(2)	Size, thickening agent	36.
Sodium Hydrosulfite	(2)	$Na_2S_2O_4$; reducing, stripping	22.
Softener Cream 25%	(2)	Sulfonated tallow oil; finishing	39.
Special Textile Flakes	(2)	Sodium salt of fatty acid; detergent	112.
Surfactant DN–40	(6)	Scouring	15.
Sulfanole KB	(3)	Sodium alkylarylsulfonate	0.
Sulfonated Castor Oil	(1)	Castor oil, sulfonated	52.
Sulfuric Acid	(1)	H_2SO_4; dyeing	0.
Stymer S	(1)	Styrene maleic anhydrous salt; size, spinning and carding oils	1.
Tall Oil Soap	(6)	Soap	147.
Tallow	(2)	Tallow; soap making	152.
Tergitol 4	(3)	$C_4H_9CH\ (C_2H_5)\ C_2H_4CH\ (SO_4Na)\ CH_2CH\ (CH_3)_2$	0.
Triethanolamine	(2)	$(HOCH_2CH_2)3N$; emulsifier, dispersing agent	1; 0.
Triton X–100	(1)(5)	Alkylarylpolyether alcohol	0.15,0.2.
Ucon H–6	(1)	Polyalkalene glycols; size, spinning and carding oils	4.
Ultrawet 60L	(1)	Sodium alkylarylsulfonate; wetting, detergent	0.24

Wheat Starch	(2)	Starch; printing inks, size	55.
Wool Oil (mineral oil + base)	(6)	Spinning	3.
Zelan AP Paste	(2)	High molecular nitrogen compounds; durable water repellent	19.
Zelec NK	(7)	Nondurable antistatic agent	54.

*Calculated from the theoretical BOD and the published percent of theoretical.
**The dye color interfered with the determination.
†New biodegradable type.
+Believed to be low since sample was very old.

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NOTE:

An expanded list of chemicals and BOD appeared in the August 29, 1966 Proceeding of the American Association of Textile Chemists and Colorists on pages 685 to 688.

APPENDIX E

ATMI – CRI WASTEWATER SURVEY

The following tabulations represent the results of a comprehensive survey of the industry performed in 1972. The survey was conducted using questionnaires distributed to members of ATMI and CRI, and by collection and analysis of mill effluent samples taken from selected plants. The field testing program was performed in an effort to validate questionnaire data and to help better characterize textile process discharges. (Note: Subcategory 7 has been omitted because no data input was available.)

To aid in this Appendix, the terms denoted are described. "Number" refers to the number of textile mills responding. The number of observations from each plant were averaged to obtain the single plant input. "Maximum" denotes the largest value of plant inputs. Likewise, "Minimum" denotes the smallest value for the plant inputs. "Average" is the mathematical mean of all the single plant values while "standard deviation" is the population deviation. A discussion of the methodology used by ATMI and CRI is included in the "Blue Book".

ATMI–CRI WASTEWATER SURVEY

CATEGORY 1 – WOOL SCOURING

		mg/l		mg/l
BOD				
Number = 3	Maximum =	7,900	Average =	3,739
	Minimum =	1,630	Std. Dev. =	3,604
COD				
Number = 3	Maximum =	31,600	Average =	15,268
	Minimum =	3,105	Std. Dev. =	14,698
TOC				
Number = 1	Maximum =	2,816	Average =	2,816
	Minimum =	2,816	Std. Dev. =	––
OIL				
Number = 3	Maximum =	6,500	Average =	3,195
	Minimum =	1,106	Std. Dev. =	2,896
pH				
Number = 3	Maximum =	7.50	Average =	7.23
	Minimum =	6.70	Std. Dev. =	0.46
ALKALINITY				
Number = 3	Maximum =	1,900	Average =	993
	Minimum =	42	Std. Dev. =	930
SUSPENDED SOLIDS				
Number = 3	Maximum =	9,500	Average =	6,595
	Minimum =	4,880	Std. Dev. =	2,529
DISSOLVED SOLIDS				
Number = 3	Maximum =	12,800	Average =	9,987
	Minimum =	7,405	Std. Dev. =	2,705
VOLATILE SOLIDS				
Number = 3	Maximum =	10,285	Average =	7,863
	Minimum =	5,904	Std. Dev. =	2,227
PHENOL				
Number = 3	Maximum =	2.00	Average =	0.87
	Minimum =	0.00	Std. Dev. =	1.02
SULFIDES				
Number = 1	Maximum =	0.10	Average =	0.10
	Minimum =	0.10	Std. Dev. =	––
WATER USE (Gal/lb.)				
Number = 5	Maximum =	20.00	Average =	7.45
	Minimum =	2.10	Std. Dev. =	6.76

ATMI–CRI WASTEWATER SURVEY

CATEGORY 2 – WOOL FINISHING

mg/l mg/l

BOD
Number = 1 Maximum = 125 Average = 125
Minimum = 125 Std. Dev. = ——

DO
Number = 1 Maximum = 5.92 Average = 5.92
Minimum = 5.92 Std. Dev. = ——

pH
Number = 1 Maximum = 6.92 Average = 6.92
Minimum = 6.92 Std. Dev. = ——

SUSPENDED SOLIDS
Number = 1 Maximum = 31 Average = 31
Minimum = 31 Std. Dev. = –

VOLATILE SOLIDS
Number = 1 Maximum = 27 Average = 27
Minimum = 27

WATER USE (Gal/lb.)
Number = 3 Maximum = 20.00 Average = 13.83
Minimum = 9.00 Std. Dev. = 4.59

ATMI–CRI WASTEWATER SURVEY

CATEGORY 3 – GREIGE MILL

mg/l mg/l

BOD
Number = 7 Maximum = 362 Average = 274
Minimum = 78 Std. Dev. = 123

COD
Number = 6 Maximum = 996 Average = 871
Minimum = 425 Std. Dev. = 230

TOC
Number = 2 Maximum = 129 Average = 119
Minimum = 108 Std. Dev. = 15

DO
Number = 4 Maximum = 3.72 Average = 3.72
Minimum = 3.72 Std. Dev. = ——

pH
Number = 7 Maximum = 23.23 Average = 11.53
Minimum = 6.23 Std. Dev. = 5.78

ALKALINITY
Number = 7 Maximum = 1928 Average = 1131
Minimum = 41 Std. Dev. = 994

SUSPENDED SOLIDS
Number = 6 Maximum = 408 Average = 87
Minimum = 2 Std. Dev. = 163

DISSOLVED SOLIDS
Number = 2 Maximum = 234 Average = 225
Minimum = 216 Std. Dev. = 13

VOLATILE SOLIDS
Number = 1 Maximum = 242 Average = 242
Minimum = 242 Std. Dev. = ––

TOTAL CHROME
Number = 5 Maximum = 10.81 Average = 8.65
Minimum = 0.03 Std. Dev. = 4.82

SULFIDES
Number = 4 Maximum = 8.00 Average = 8.00
Minimum = 8.00 Std. Dev. = ––

WATER USE (Gal/lb.)
Number = 30 Maximum = 4.70 Average = 1.51
Minimum = 0.08 Std. Dev. = 1.52

ATMI–CRI WASTEWATER SURVEY

CATEGORY 4 – WOVEN FABRIC FINISHING

mg/l mg/l

BOD
Number = 21 Maximum = 1800 Average = 592
Minimum = 134 Std. Dev. = 392

COD
Number = 13 Maximum = 2288 Average = 1093
Minimum = 378 Std. Dev. = 513

DO
Number = 10 Maximum = 9.43 Average = 3.04
Minimum = 0.00 Std. Dev. = 3.17

COLOR
Number = 6 Maximum = 692 Average = 389
Minimum = 115 Std. Dev. = 207

OIL
Number = 1 Maximum = 14 Average = 14
Minimum = 14 Std. Dev. = –

pH Number = 21 Maximum = 23.22 Average = 11.62
Minimum = 7.50 Std. Dev. = 2.89

ALKALINITY

Number = 14   Maximum = 1928   Average = 706
Minimum = 26   Std. Dev. = 597

SUSPENDED SOLIDS

Number = 16   Maximum = 2180   Average = 313
Minimum = 0   Std. Dev. = 533

DISSOLVED SOLIDS

Number = 11   Maximum = 4296   Average = 1975
Minimum = 228   Std. Dev. = 1195

VOLATILE SOLIDS

Number = 11   Maximum = 3228   Average = 960
Minimum = 83   Std. Dev. = 977

TOTAL CHROME

Number = 8   Maximum = 10.81   Average = 4.30
Minimum = 0.31   Std. Dev. = 4.23

PHENOL

Number = 3   Maximum = 0.02   Average = 0.01
Minimum = 0.00   Std. Dev. = 0.01

SULFIDES

Number = 3   Maximum = 8.00   Average = 2.72
Minimum = 0   Std. Dev. = 4.57

WATER USE (Gal/lb.)

Number = 29   Maximum = 40.73   Average = 18.14
Minimum = 3.87   Std. Dev. = 9.93

ATMI–CRI WASTEWATER SURVEY

CATEGORY 5 – KNIT FABRIC FINISHING

mg/l   mg/l

BOD

Number = 6   Maximum = 800   Average = 355
Minimum = 80   Std. Dev. = 303

COD

Number = 3   Maximum = 1501   Average = 1105
Minimum = 869   Std. Dev. = 345

TOC

Number = 1   Maximum = 250   Average = 250
Minimum = 250   Std. Dev. = –

DO

Number = 2   Maximum = 4.00   Average = 3.96
Minimum = 3.93   Std. Dev. = 0.05

COLOR

Number = 3   Maximum = 2500   Average = 1295
Minimum = 625   Std. Dev. = 1046

OIL
Number = 1 Maximum = 53 Average = 53
Minimum = 53 Std. Dev. = –

pH
Number = 5 Maximum = 9.19 Average = 6.90
Minimum = 3.95 Std. Dev. = 2.05

ALKALINITY
Number = 3 Maximum = 149 Average = 68
Minimum = 0 Std. Dev. = 75

SUSPENDED SOLIDS
Number = 5 Maximum = 332 Average = 115
Minimum = 40 Std. Dev. = 123

DISSOLVED SOLIDS
Number = 3 Maximum = 2275 Average = 1225
Minimum = 684 Std. Dev. = 909

VOLATILE SOLIDS
Number = 3 Maximum = 464 Average = 373
Minimum = 306 Std. Dev. = 82

PHENOL
Number = 1 Maximum = 23.00 Average = 23.00
Minimum = 23.00 Std. Dev. = – –

WATER USE (Gal/lb.)
Number = Maximum = 40.20 Average = 20.25
Minimum = 6.00 Std. Dev. = 9.77

ATMI–CRI WASTEWATER SURVEY

CATEGORY 6 – GREIGE MILL PLUS WOVEN FABRIC FINISHING

mg/1 mg/1

BOD
Number = 10 Maximum = 2200 Average = 636
Minimum = 28 Std. Dev. = 618

COD
Number = 5 Maximum = 1822 Average = 1266
Minimum = 295 Std. Dev. = 620

ALKALINITY
Number = 6 Maximum = 782 Average = 519
Minimum = 342 Std. Dev. = 205

SUSPENDED SOLIDS
Number = 6 Maximum = 390 Average = 232
Minimum = 46 Std. Dev. = 136

DISSOLVED SOLIDS
Number = 3 Maximum = 2542 Average = 2062
Minimum = 1513 Std. Dev. = 518

VOLATILE SOLIDS
Number = 3 Maximum = 749 Average = 727
Minimum = 700 Std. Dev. = 25

TOTAL CHROME
Number = 4 Maximum = 8.70 Average = 4.54
Minimum = 0.02 Std. Dev. = 4.81

PHENOL
Number = 1 Maximum = 0.06 Average = 0.06
Minimum = 0.06 Std. Dev. = –

SULFIDES
Number = 1 Maximum = 0.10 Average = 0.10
Minimum = 0.10 Std. Dev. = –

WATER USE (Gal/lb.)
Number = 15 Maximum = 76.00 Average = 15.74
Minimum = 2.50 Std. Dev. = 18.60

ATMI–CRI WASTEWATER SURVEY

CATEGORY 8 – INTEGRATED CARPET MILL

mg/1 mg/1

BOD
Number = 9 Maximum = 309 Average = 177
Minimum = 47 Std. Dev. = 73

COD
Number = 9 Maximum = 2264 Average = 852
Minimum = 531 Std. Dev. = 584

ALKALINITY
Number = 5 Maximum = 204 Average = 134
Minimum = 91 Std. Dev. = 55

SUSPENDED SOLIDS
Number = 4 Maximum = 88 Average = 75
Minimum = 48 Std. Dev. = 19

DISSOLVED SOLIDS
Number = 4 Maximum = 1780 Average = 754
Minimum = 360 Std. Dev. = 690

VOLATILE SOLIDS
Number = 4 Maximum = 1099 Average = 460
Minimum = 176 Std. Dev. = 429

TOTAL CHROME
Number = 2 Maximum = 0.42 Average = 0.42
Minimum = 0.42 Std. Dev. = ——

PHENOL
Number = 2 Maximum = 0.13 Average = 0.13
Minimum = 0.13 Std. Dev. = ——

WATER USE (Gal/lb.)
Number = 38 Maximum = 17.00 Average = 7.49
Minimum = 1.81 Std. Dev. = 4.67

ATMI–CRI WASTEWATER SURVEY

CATEGORY 9 – STOCK AND YARN DYEING AND FINISHING

mg/l mg/l

BOD
Number = 9 Maximum = 600 Average = 240
Minimum = 73 Std. Dev. = 166

COD
Number = 2 Maximum = 1400 Average = 882
Minimum = 363 Std. Dev. = 733

DO
Number = 4 Maximum = 5.53 Average = 2.68
Minimum = 0 Std. Dev. = 3.10

COLOR
Number = 4 Maximum = 12 Average = 12
Minimum = 12 Std. Dev. = –

pH
Number = 9 Maximum = 11.80 Average = 8.93
Minimum = 4.52 Std. Dev. = 2.60

ALKALINITY
Number = 3 Maximum = 2730 Average = 1037
Minimum = 187 Std. Dev. = 1466

SUSPENDED SOLIDS
Number = 5 Maximum = 160 Average = 77
Minimum = 22 Std. Dev. = 69

DISSOLVED SOLIDS
Number = 2 Maximum = 2100 Average = 1869
Minimum = 1639 Std. Dev. = 326

VOLATILE SOLIDS
Number = 2 Maximum = 1140 Average = 586
Minimum = 32 Std. Dev. = 783

TOTAL CHROME
Number = 1 Maximum = 0.27 Average = 0.27
Minimum = 0.27 Std. Dev. = –

WATER USE (Gal/lb.)
Number = 33 Maximum = 81.89 Average = 22.26
Minimum = 1.68 Std. Dev. = 17.38

ATMI–CRI WASTEWATER SURVEY

CATEGORY 10 – GREIGE MILL PLUS FINISHING YARN AND FABRICS

mg/l mg/l

BOD
Number = 6 Maximum = 566 Average = 355
Minimum = 123 Std. Dev. = 179

COD
Number = 2 Maximum = 500 Average = 422
Minimum = 344 Std. Dev. = 110

COLOR
Number = 2 Maximum = 692 Average = 671
Minimum = 650 Std. Dev. = 30

OIL
Number = 1 Maximum = 216 Average = 216
Minimum = 216 Std. Dev. = –

pH
Number = 6 Maximum = 11.20 Average = 9.69
Minimum = 6.50 Std. Dev. = 1.76

ALKALINITY
Number = 3 Maximum = 304 Average = 219
Minimum = 67 Std. Dev. = 132

SUSPENDED SOLIDS
Number = 5 Maximum = 261 Average = 114
Minimum = 20 Std. Dev. = 98

DISSOLVED SOLIDS
Number = 2 Maximum = 1700 Average = 1489
Minimum = 1277 Std. Dev. = 299

VOLATILE SOLIDS
Number = 2 Maximum = 188 Average = 166
Minimum = 143 Std. Dev. = 32

TOTAL CHROME
Number = 2 Maximum = 1.53 Average = 0.77
Minimum = 0 Std. Dev. = 1.08

PHENOL
Number = 1   Maximum = 0.07   Average = 0.07
Minimum = 0.07   Std. Dev. = –

WATER USE (Gal/lb.)
Number = 8   Maximum = 28.91   Average = 15.06
Minimum = 4.56   Std. Dev. = 7.71

ATMI–CRI WASTEWATER SURVEY

CATEGORY 11 – COMBINED MATERIALS FINISHED, STOCK, YARN, WOVENS, KNITS

mg/l   mg/l

BOD
Number = 10   Maximum = 807   Average = 381
Minimum = 73   Std. Dev. = 286

COD
Number = 6   Maximum = 2149   Average = 986
Minimum = 310   Std. Dev. = 672

COLOR
Number = 4   Maximum = 7500   Average = 3013
Minimum = 12   Std. Dev. = 3175

OIL
Number = 2   Maximum = 15   Average = 8
Minimum = 1   Std. Dev. = 11

pH
Number = 10   Maximum = 12.00   Average = 8.64
Minimum = 5.30   Std. Dev. = 2.37

ALKALINITY
Number = 6   Maximum = 1315   Average = 492
Minimum = 11   Std. Dev. = 476

SUSPENDED SOLIDS
Number = 8   Maximum = 350   Average = 101
Minimum = 22   Std. Dev. = 105

DISSOLVED SOLIDS
Number = 7   Maximum = 4302   Average = 1916
Minimum = 504   Std. Dev. = 1509

VOLATILE SOLIDS
Number = 4   Maximum = 1656   Average = 552
Minimum = 39   Std. Dev. = 747

TOTAL CHROME
Number = 4   Maximum = 5.00   Average = 1.32
Minimum = 0.00   Std. Dev. = 2.45

PHENOL
Number = 2 Maximum = 0.51 Average = 0.28
Minimum = 0.05 Std. Dev. = 0.33

SULFIDES
Number = 1 Maximum = 0.60 Average = 0.60
Minimum = 0.60 Std. Dev. = –

WATER USE (Gal/lb.)
Number = 16 Maximum = 69.58 Average = 32.32
Minimum = 12.00 Std. Dev. = 16.61

ATMI–CRI WASTEWATER SURVEY

CATEGORY 12 – MULTIPLE OPERATION COMMISSION HOUSE

mg/1 mg/1

BOD
Number = 4 Maximum = 277 Average = 190
Minimum = 44 Std. Dev. = 102

COD
Number = 2 Maximum = 904 Average = 704
Minimum = 504 Std. Dev. = 283

DO Number = 3 Maximum = 10.4 Average = 7.39
Minimum = 5.8 Std. Dev. = 2.61

COLOR
Number = 1 Maximum = 115 Average = 115
Minimum = 115 Std. Dev. = –

pH
Number = 4 Maximum = 11.70 Average = 9.25
Minimum = 6.19 Std. Dev. = 2.82

ALKALINITY
Number = 3 Maximum = 873 Average = 476
Minimum = 96 Std. Dev. = 388

SUSPENDED SOLIDS
Number = 2 Maximum = 42 Average = 27
Minimum = 12 Std. Dev. = 21

DISSOLVED SOLIDS
Number = 2 Maximum = 232 Average = 1523
Minimum = 722 Std. Dev. = 1133

VOLATILE SOLIDS
Number = 1 Maximum = 1052 Average = 1052
Minimum = 1052 Std. Dev. = ––

TOTAL CHROME
Number = 1 Maximum = 2.13 Average = 2.13
Minimum = 2.13 Std. Dev. = ––

WATER USE (Gal/lb.)
Number = 3 Maximum = 75.00 Average = 42.60
Minimum = 18.00 Std. Dev. = 19.92

ATMI–CRI WASTEWATER SURVEY

CATEGORY 13 – SPECIALIZED FINISHING

mg/l mg/l

BOD
Number = 2 Maximum = 362 Average = 272
Minimum = 182 Std. Dev. = 127

COD
Number = 1 Maximum = 996 Average = 996
Minimum = 996 Std. Dev. = –

ALKALINITY
Number = 1 Maximum = 1928 Average = 1928
Minimum = 1928 Std. Dev. = –

SUSPENDED SOLIDS
Number = 2 Maximum = 719 Average = 360
Minimum = 2 Std. Dev. = 507

DISSOLVED SOLIDS
Number = 1 Maximum = 551 Average = 551
Minimum = 551 Std. Dev. = –

VOLATILE SOLIDS
Number = 1 Maximum = 352 Average = 352
Minimum = 352 Std. Dev. = –

TOTAL CHROME
Number = 1 Maximum = 10.81 Average = 10.81
Minimum = 10.81 Std. Dev. = –

SULFIDES
Number = 1 Maximum = 8.00 Average = 8.00
Minimum = 8.00 Std. Dev. = –

WATER USE (Gal/lb.)
Number = 2 Maximum = 1.30 Average = 0.76
Minimum = 0.23 Std. Dev. = 0.53

APPENDIX F

NATIONAL COMMISSION ON WATER QUALITY SURVEY

AVERAGE RAW WASTE CHARACTERISTICS
(30 Day Average)

Subcategory	1	2.3	4	5	6.7	8.9	10	11
Water Use (Gal/lb.)	4.3	40	1.5	1.5	13.5	18	8.3	18
Production (Med. Size)*	80	2-20 3-20	60	105	6-180 7-15	8-40 9-60	60	60
lbs/1000 lbs Product								
BOD_5	(170-233) 195	(50-233) 100	(1.0-5.8) 3.7	(1-3.1) 1.8	(28-95.7) 62	(15-97.6) 37.5	(10-43.6) 23.5	(11.3-51.0) 30
TSS	(180-878) 269	(15-100) 43	(0.6-4.5) 1.9	(6.3-12.5) 6.9	(5.1-53.5) 21	(6.0-72.8) 45	(5.2-10.3) 8.3	(3.8-11.3) 7.35
COD	(1061-1122) 1094	(93-1670) 347	(4.0-25) 12.0	(18.8-37.5) 23.8	(47.9-162) 95.7	(67.6-255) 127.6	(39.5-94.1) 64	(33-151.6) 78.7
Oil & Grease	(179-201) 191	—	—	—	—	—	—	—
Total Chromium	0.002	1.3	—	—	0.0045	0.0072	NI	0.002
Phenol	0.054	0.17	—	—	0.0045	0.04	NI	0.018
Sulfide	0.001	0.03	—	—	0.31	0.03	NI	NI
Color (ADMI Units)	900-2500	500-1700	—	800	325	400	600	600
Fecal Coliform	NI	NI	NI	NI	NI	NI	NI	NI
pH (Units)	6-9	6-11	6-11	5-7.5	7-11	6-9	6-9	7-12

NI-No Information Available
* 1000 lb./Day
( ) Range of Values

AVERAGE RAW WASTE CHARACTERISTICS
(30 Day Average)

Subcategory	1	2.3	4	5	6.7	8.9	10	11
Water Use (Gal/lb.)	4.3	40	1.5	1.5	13.5	18	8.3	18
Production (Med. Size)*	80	2-20 3-20	60	105	6-180 7-15	8-40 9-60	60	60
mg/l								
BOD$_5$	(4740-6220) 5480	(150-700) 300	(80-465) 300	(80-250) 140	(250-850) 550	(100-650) 250	(144-630) 340	(75-340) 200
TSS	(5000-24500) 7500	(45-300) 130	(50-360) 150	(500-1000) 550	(45-475) 185	(40-485) 300	(75-150) 120	(25-75) 50
COD	(29600-31300) 30500	(280-5000) 1041	(320-2000) 950	(1500-3000) 1900	(425-1440) 850	(450-1500) 850	(570-1360) 925	(220-1010) 524
Oil & Grease	(5000-5600) 5340	—	—	—	—	—	—	—
Total Chromium	0.05	4	—	—	0.04	0.05	NI	0.013
Phenol	1.50	0.5	—	—	0.04	0.27	NI	0.12
Sulfide	0.20	0.1	—	—	2.72	0.2	NI	NI
Color (ADMI Units)	2000	500-1700	—	800	325	400	600	600
Fecal Coliform	NI	NI	NI	NI	NI	NI	NI	NI
pH (Units)	6-9	6-11	6-11	5-7.5	7-11	6-9	6-9	7-12

NI-No Information Available
* 1000 lb./Day
( ) Range of Values

APPENDIX G

LIST OF TRADE ORGANIZATIONS & JOURNALS

AATCC – American Association of Textile Chemists & Colorists
P. O. Box 12215
Research Institute Park
North Carolina 27709
(919) 549-8141

ADMI – American Dye Manufacturers Institute, Inc.
74 Trinity Place
New York, New York 10006
(212) 421-9390

ATMI – American Textile Manufacturers Institute, Inc.
1501 Johnston Building
Charlotte, North Carolina 28201
(704) 334-4734

CRI – Carpet & Rug Institute
P. O. Box 2048
Dalton, Georgia 30720
(404) 278-3176

ITT – Institute of Textile Technology
P. O. Box 391
Charlottesville, Virginia 22902
(804) 296-5511

TRI – Textile Research Institute
P. O. Box 625
Princeton, New Jersey 08540
(609) 924-3150

NTA – Northern Textile Association
211 Congress Street
Boston, Massachusetts 02110
(617) 542-8220

TRADE JOURNALS

1. American Dye Stuff Reporter
2. America's Textiles
3. American Textile Reporter
4. Daily News Record
5. Modern Textiles
6. Textile Chemist & Colorist
7. Textile Industry
8. Textile World

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